Scanning the Issue

Toward Effective Traffic Sign Detection via Two-Stage Fusion Neural Networks

Z. Li, H. Chen, B. Biggio, Y. He, H. Cai, F. Roli, and L. Xie

Automatic detection of traffic signs is crucial for advanced driving assistance systems (ADASs). Current two-stage approaches consist of a preliminary object detection step, where the traffic signs are categorized within broader families (e.g., speed limits), and then sub-classes (e.g., speed limit 40). However, these cascading methods fail to achieve satisfying performance, especially in more realistic driving scenarios where images are acquired under more challenging conditions. Under such conditions, the first-stage detection step is likely to provide inaccurate predictions, making the subsequent classification step useless. In this article, the authors propose a simple yet effective two-stage fusion framework for traffic sign detection. Different from the previous cascading method, the framework directly predicts categories in the first-stage detection and fuses the two-stage category predictions to improve overall robustness. Besides, in order to filter the false detection boxes under low-resolution inputs, they also propose an effective post-processing method called surrounding-aware non-maximum suppression (SA-NMS) as an alternative technique for first-stage detection. After combining the above-proposed methods, the framework obtains good detection performance. The experimental results on the widely used Tsinghua-Tencent 100K (TT100K) traffic sign dataset, which contains images of traffic signs collected under a variety of challenging conditions, show that the proposed framework outperforms current approaches in both accuracy and inference speed, achieving 89.7 mAP and 65 FPS for 608 608 low-resolution images.

Post-Impact Stability Control for Road Vehicles: State-of-the-Art Methodologies and Perspectives

C. Wang, Z. Wang, L. Zhang, J. Chen, and D. Cao

Reducing traffic accidents and associated casualties is a growing concern for modern human society. The secondary or even chain collisions for an unstable vehicle after an initial impact can result in more hazards and fatalities. Passive safety systems such as airbags and seat belts only provide a limited level of protection for vehicle occupants, but cannot prevent collision accidents, while active safety systems usually work before the initial collision. Therefore, it is of great significance to develop dedicated post-impact stability control systems to help vehicles quickly restore stability to mitigate and/or avoid secondary collisions. However, the loss of the original nonholonomic constraint property and the nonlinearity and saturation of tire forces due to post-impact sideslip, over-spinning, and drifting motions pose great challenges in controller design. Moreover, how to simulate and analyze the collision process and further construct a simulation environment is the primary problem to solve for enabling controller development. Also, exploring repeatable, effective, and low-cost experiment methods lays the foundation for controller verification. This article aims to provide an overview of the latest technological advancements in collision modeling, control synthesis, and experimental procedures for post-impact stability control. The advantages and disadvantages of different modeling, control, and experimental approaches are compared in succession. Finally, the article discusses the challenges encountered in existing research and the prospects for post-impact active safety control systems.

A Survey of Computation Offloading With Task Types

S. Zhang, N. Yi, and Y. Ma

The survey seeks to classify the state-of-the-art (SoTA) in computation offloading from the perspective of task types. A thorough literature review is conducted to reveal the SoTA from various aspects, including architecture, objective, offloading strategy, and task types, with the consideration of task generation. It has been observed that task types are associated with data and have an impact on the offloading process, including elements like resource allocation and task assignment. Building upon this insight, computation offloading is categorized into two groups based on task types: static task-based offloading and dynamic task-based offloading. Finally, a prospective view of the challenges and opportunities in the field of future computation offloading is presented.

Behavioral Intention Prediction in Driving Scenes: A Survey

J. Fang, F. Wang, J. Xue, and T.-S. Chua

In driving scenes, road agents often engage in frequent interaction and strive to understand their surroundings. Ego-agent (each road agent itself) predicts what behavior will be engaged by other road users all the time and expects a shared and consistent understanding for safe movement. To achieve this, behavioral intention prediction (BIP) simulates such a human consideration process to anticipate specific behaviors, and the rapid development of BIP inevitably leads to new issues and challenges. To catalyze future research, this work provides a comprehensive review of BIP from the available datasets, key factors, challenges, pedestrian-centric and vehicle-centric BIP approaches, and BIP-aware applications. The investigation reveals that data-driven deep learning approaches have become the primary pipelines, while the behavioral intention types are still limited in most current datasets and methods (e.g., crossing (C) and not crossing (NC) for pedestrians and lane changing (LC) for vehicles) in this field. In addition,

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current research on BIP in safe-critical scenarios (e.g., near-crashing situations) is limited. Through this investigation, the authors identify open issues in BIP and suggest possible insights for future research.

Review of Accident Detection Methods Using Dashcam Videos for Autonomous Driving Vehicles

A. Rocky, Q. J. Wu, and W. Zhang

The need for a reliable system to detect high-risk incidents in complex settings like roadways, which are infrequent but potentially dangerous, has arisen due to the occurrence of rare hazardous events. This system would empower self-driving cars to function autonomously over extended periods without human involvement. Among these hazardous occurrences, accidents have received the least attention due to their rarity and diverse nature. Recently, dashboard cameras (dashcams) have gained recognition in academic circles as a cost-effective and accessible solution to enhance the safety of autonomous vehicles when handling accidents, since they are now commonly found in most vehicles. This review presents the progression of concepts in this domain, tracing its development from early ideas to cutting-edge techniques. It categorizes these approaches into supervised, self-supervised, and unsupervised learning. Furthermore, the review thoroughly examines evaluation criteria and available datasets, providing a comprehensive comparison of the strengths and limitations of different methods. Ultimately, the review proposes potential avenues for future research in this field.

A Scalable Approach to Detecting Safety Requirements Inconsistencies for Railway Systems

X. Chen, Z. Jin, M. Zhang, F. Mallet, X. Liu, and T. Zhou

In light of the scalability challenges faced by current inconsistency analysis techniques for railway safety requirements, the authors propose a two-layer static approach to detect inconsistencies in the time-related safety requirements of railway systems. They have pragmatically integrated two distinct formal methods, utilizing conflict pattern matching and graph search techniques. At the SafeNL layer, they employ an SMT-based approach to extract conflict patterns and use them to filter out inconsistent requirements descriptions, thus avoiding the more expensive general use of the SMT-based approach. Furthermore, at the CCSL layer, temporal dependencies in the requirements are transformed into causal relations, followed by the application of graph search techniques to detect circular inconsistencies. This research can serve as a model for industry companies seeking practical solutions to the challenges of applying formal methods to their requirement engineering problems.

Public Transit for Special Events: Ridership Prediction and Train Scheduling

T. Santanam, A. Trasatti, P. Van Hentenryck, and H. Zhang

This article proposes a methodology to help transit agencies with their tactical planning for post-game ridership of large events. The methodology involves predicting total post-game ridership, combining it with historical trends to forecast the passenger flow curve at nearby stations, and estimating the required train frequencies. In addition, this article proposes a suite of data-driven techniques that together create a data-driven pipeline to exploit automated fare collection (AFC) data for evaluating, anticipating, and managing the performance of transit systems. A case study using real-world data from the metropolitan Atlanta rapid transit authority (MARTA) demonstrates the effectiveness of the proposed methodology in improving post-game congestion and wait time.

Vehicular Edge Computing Meets Cache: An Access Control Scheme With Fair Incentives for Privacy-Aware Content Delivery

S. Jiang, J. Li, G. Sang, H. Wu, and Y. Zhou

Vehicular edge computing (VEC) merges mobile edge computing with vehicular networks, offloading computation and storage from resource-constrained vehicles to edge nodes. Vehicle mobility causes frequent network changes, complicating data sharing. Cache-based content delivery is a potential solution for efficient sharing in such dynamic settings. Prior studies often overlook access control and fair incentive mechanisms in privacy-aware data sharing. This article introduces RFIP-VEC, a revocable access control scheme with fair incentives for privacy-aware content delivery. The authors devise a secure group signature scheme for anonymous authentication and conditional revocation, underpinned by formal security proofs. Utilizing proxy re-encryption, they establish a two-layer access control framework. An evolutionary game theory model evaluates the fairness and effectiveness of the incentive mechanisms. The scheme ensures flexible access control and fair incentives with edge node support. Security analyses and experimental results confirm the proposed scheme's achievement of security objectives with minimal performance overhead in VEC networks.

Current Effect-Eliminated Optimal Target Assignment and Motion Planning for a Multi-UUV System

D. Zhu and S. X. Yang

An innovative approach for optimizing target assignment and motion planning in a multi-UUV system amidst ocean currents is proposed. It integrates a bio-inspired neural network (BINN) for path prediction and collision avoidance and incorporates an optimal target assignment component based on BINN-derived path distances. In addition, the ocean's current disruptions are addressed through the seamless integration of an adjusted component. The simulation results demonstrate the approach's effectiveness under both static and dynamic ocean current effects.

Speed Reduction Measure Based on Nudging Using Real-Time Vehicle Trajectory Acquisition With Thermal Cameras

M. Berghaus, A. Fazekas, K. Lukas, M. Schwalm, and M. Oeser

Accident risk and severity are closely associated with speeding. Reducing vehicles' speeds can contribute to road traffic safety. Conventional speed reduction measures, such as speed limit enforcement or speed indicator devices, only have a local effect, so they are not suitable for longer road stretches with varying speed limits, e.g., narrow curves in motorway exits. The authors present a novel speed reduction measure based on the concept of "nudging." The measure consists of LEDs embedded in the road marking that light up in front of vehicles that exceed a predefined speed threshold. The speeds and positions of the vehicles are gathered in real-time by thermal cameras and computer vision algorithms in order to target and follow only the speeding vehicles without distracting other drivers. The speed reduction measure was implemented and evaluated at a motorway exit with a narrow curve in Eindhoven, the Netherlands. The effectiveness was analyzed using linear regression models in order to take external influences on the speed (e.g., daylight and weather) into account. The mean speed was reduced by up to 2.7 km/h and the ratio of speeding vehicles by up to 40%. The most substantial speed reduction was observed on the straight part of the exit lane, which means that drivers decelerate earlier in front of the curve rather than in the curve, where longitudinal and lateral acceleration would overlap.

Joint Partial Offloading and Resource Allocation for Vehicular Federated Learning Tasks

G. Ma, M. Hu, X. Wang, H. Li, Y. Bian, K. Zhu, and Di Wu

This article proposes a distributed approach that confronts the multi-variable non-convex challenge directly by decoupling variables and deriving constraint-based bounds that guide the decisions for offloading and allocation. A novel low-complexity distributed algorithm is introduced that not only tends toward optimal but also demonstrates superior real-time applicability and efficiency. By integrating with the federated learning framework, the algorithm's practical effectiveness addresses a notable gap between the theoretical models for computation offloading and actual real-life execution, reinforcing the soundness and relevance of the proposed method.

Fine-Grained Vehicle Make and Model Recognition Framework Based on Magnetic Fingerprint

H. Zhang, W. Zhou, G. Liu, Z. Wang, and Z. Qian

Fine-grained vehicle classification of make and model recognition is of practical significance and can be widely applied in tasks such as traffic perception and control. To date, vision-based vehicle make and model recognition methods have improved through the years; however, they often fail in low-visibility scenes. This article proposes a fine-grained vehicle model recognition framework based on magnetic fingerprints instead of videos from surveillance cameras. The magnetic fingerprint refers to the pattern of magnetic field data obtained when vehicles pass magnetic sensors, which have less sensitivity and more robustness towards low-visibility scenes than surveillance cameras. Specifically, the proposed framework first utilizes adversarial autoencoders to extract the magnetic fingerprint from the raw magnetic field data, keeping detailed information for fine-grained vehicle model recognition as complete as possible. Then, an AdaBoostSVM algorithm is used to identify vehicle models from the magnetic fingerprint and further alleviate the hard-negative issue to reduce false classifications. The massive experimental results show that the proposed fine-grained vehicle magnetic fingerprint/AdaBoostSVM method achieves state-of-the-art results on fine-grained vehicle make and model recognition. The average precision reached 94.3% and the average recall reached 94.2% in the dataset containing 36 vehicle models in total. Notably, the proposed method outperforms surveillance camera methods, especially in low-visibility scenes, making it a valuable addition to future intelligent transportation systems.

Stackelberg Differential Lane Change Game Based on MPC and Inverse MPC

Q. Zhang, R. Langari, H. E. Tseng, S. Mohan, S. Szwabowski, and D. Filev

A Stackelberg differential game theoretic model predictive controller (MPC) is proposed for an autonomous highway driving problem. The hierarchical controller's high-level component is the two-player Stackelberg differential lane change game, where each player uses an MPC to control his/her own motion. The differential game is converted into a bi-level optimization problem and is solved with the branch and bound algorithm. In addition, an inverse MPC algorithm is developed to estimate the weights of the MPC cost function of the target vehicle. The low-level hybrid MPC controls both the autonomous vehicle's longitudinal motion and its real-time lane determination. Simulations indicate both the inverse MPC's capability on aggressiveness estimation of target vehicles and DGTMPC's superior performance in interactive lane change situations.

"To Lane or Not to Lane?"—Comparing On-Road Experiences in Developing and Developed Countries Using a New Simulator RoadBird

M. M. Mushfiq, T. R. Toha, S. I. Salim, A. Mostak, M. Rahaman, N. A. Al-Nabhan, A. M. Sadri, and A. B. M. A. A. Islam

This study explores the differences between lane-based and non-lane-based traffic systems in developing and developed countries using the new traffic simulator RoadBird. By analyzing real road topologies from cities like Dhaka, Miami, and Riyadh, the research investigates various traffic scenarios, including lane-based and non-lane-based flows, homogeneous and heterogeneous traffic, and the presence of pedestrians. The findings reveal that lane-based approaches do not consistently outperform non-lane-based strategies, especially in mixed traffic conditions, and highlight the potential benefits of non-lane-based methods in lane-based contexts. This work provides new insights into traffic system performance and the complex dynamics of on-road experiences in different global contexts.

Finite-Time Distributed Adaptive Coordinated Control for Multiple Traction Units of High-Speed Trains

D. Wang, S. Su, L. Han, and D. Li

This article investigates a coordinated control approach of a high-speed train to reduce the interaction force between successive traction units. A finite-time coordinated control protocol is designed based on the principle of multi-agent control and the finite-time Lyapunov stability theorem.

The developed protocol demonstrates robustness to disturbances, ensuring a speed consensus among all traction units. Furthermore, it guarantees that the interaction forces between successive traction units converge to zero within a finite time frame, highlighting a significant step forward in the operational efficiency and safety of high-speed rail systems.

Proactive Content Retrieval Based on Value of Popularity in Content-Centric Internet of Vehicles

M. T. R. Khan, Y. Z. Jembre, M. M. Saad, S. H. Bouk, S. H. Ahmed, and D. Kim

Content retrieval in content-centric vehicular networks faces challenges that include high latency, especially when content is stored far from the requesting vehicle. On-path caching feature in the conventional vehicular named data networks (VNDNs) enables content storage that can reduce latency. However, due to the constantly changing dynamic ad hoc nature of the vehicular network, the availability of stored content for the requester vehicle cannot be guaranteed. In addition, without knowing which content will be requested, where it will be requested, and when it will be requested, the content caching functionality of VNDN is underutilized. To address this issue, this manuscript proposes a content prefetching scheme for the content-centric Internet of Vehicles (CIoV) by introducing the content value of popularity (VoP) matrix. Considering vehicles requesting the content of similar interests, the authors evaluate VoP through three value update functions that follow the power law of the time elapsed since the last content requested. By multiple parameters of consumer vehicle similarity, an on-road proactive content retriever vehicle is selected. The simulation results showed that the proposed proactive on-path content prefetching mechanism significantly reduces the content delivery delay while increasing the success delivery ratio by 48% and extends the spread of content within the network by 53%.

VoPiFNet: Voxel-Pixel Fusion Network for Multi-Class 3D Object Detection

C.-H. Wang, H.-W. Chen, Y. Chen, P.-Y. Hsiao, and L.-C. Fu

Due to the failure to exploit image semantics, many LiDAR-based methods do not outperform fusion-based approaches in detecting small targets or under challenging conditions. This article proposes a multi-modal and multi-class 3-D object detection network, named voxel-pixel fusion network (VoPiFNet). Within this network, the authors design a key novel component called the voxel-pixel fusion layer, which leverages the geometric relation of a voxel-pixel pair and effectively fuses voxel features and pixel features with a cross-modal attention mechanism. Moreover, after considering the characteristics of the voxel-pixel pair, they design four parameters to guide and enhance this fusion effect. This proposed layer can be integrated with voxel-based 3-D LiDAR detectors and 2-D image detectors. Extensive experiments on the public KITTI benchmark dataset show that the method outperforms state-of-the-art methods in detecting the challenging pedestrian category and achieves promising performance in overall 3-D mean average precision (mAP).

Interactive Behavior Modeling for Vulnerable Road Users With Risk-Taking Styles in Urban Scenarios: A Heterogeneous Graph Learning Approach

Z. Li, J. Gong, Z. Zhang, C. Lu, V. L. Knoop, and M. Wang

A deep understanding of the behaviors of traffic participants is essential to guarantee the safety of automated vehicles (AVs) in mixed traffic with vulnerable road users (VRUs). Precise trajectory prediction of traffic participants can provide reasonable solution space for motion planning of AV. Early works mainly focused on handcrafting the feature representation and designing complicated architectures in deep learning-based prediction models. However, these approaches overlooked the fact that different road users perceive the safety of the same interaction differently and also exhibit heterogeneous risk-taking styles. In this article, the authors will develop a model for trajectory prediction based on risk-taking styles. The model accounts for the expected positions and occupancy of traffic participants in the surrounding environment. It consists of two sequential steps: risk-taking styles of multi-modal road users under interactive scenes are first clustered, and then reformulated in the heterogeneous graph model for trajectory prediction. The model is validated by the driving data collected on the urban road using a public dataset. Comparative experiments demonstrate that the proposed method can predict the trajectory of traffic participants much more accurately than the state-of-the-art methods.

A Lightweight Group Authentication Protocol for Blockchain-Based Vehicular Edge Computing Networks

X. Meng, B. Liu, X. Meng, Y. Liang, and H. Deng

Trust management and identity authentication in vehicular edge computing (VEC) is a critical part of data security. However, most of the existing authentication protocols fail to fully address the data trust issue among edge computing nodes in cross-regional communications and lack anonymous security features. In this article, a lightweight multi-entity authenticated group key agreement (MAGKA) protocol is proposed for blockchain-based VEC networks. The proposed blockchain network built from the road side units (RSUs) is to ensure the un-deniability of any data exchanged among the edge networks to provide data trust management. The MAGKA protocol substantiates the lightweight authentication between the vehicles, the trusted authority, and RSU anonymously, allowing the vehicles to join or leave the edge network dynamically on the premise of ensured security. The security analysis shows that the MAGKA protocol can resist common attacks effectively.

Weak TDMA for the Deterministic Medium Access on the Controller Area Network

M. Akpınar, E. G. Schmidt, and K. W. Schmidt

The article proposes weak TDMA (WTDMA) as a new method for slotted medium access on the controller area network (CAN). Different from TDMA, WTDMA does not require guard times for the temporal isolation of different time slots. Instead, a certain degree of overlap of time slots can be tolerated. Moreover, WTDMA can be realized in software with a moderate accuracy of the synchronized clocks of different CAN nodes and without any modifications to the

CAN standard. The article provides sufficient conditions for the correct operation of WTDMA and performs a comprehensive experimental evaluation. It is shown that bus loads above 90% can be achieved, whereby the message latencies are mostly determined by the message transmission times in the order of hundreds of microseconds.

Uncertainty-Aware Temporal Graph Convolutional Network for Traffic Speed Forecasting

W. Qian, T. D. Nielsen, Y. Zhao, K. G. Larsen, and J. J. Yu

Traffic speed forecasting has been a very active research area as it is essential for intelligent transportation systems. Although a plethora of deep learning methods have been proposed for traffic speed forecasting, the majority of them can only make point-wise predictions, which may not provide enough information for critical real-world scenarios where prediction confidence also needs to be estimated, e.g., route planning for ambulances and rescue vehicles. To address this issue, the authors propose a novel uncertainty-aware deep learning method coined uncertainty-aware temporal graph convolutional network (UAT-GCN). UAT-GCN employs a graph convolutional network and gated recurrent unit-based architecture to capture spatio-temporal dependencies. In addition, UAT-GCN consists of a specialized regressor for estimating both epistemic (model-related) and aleatoric (data-related) uncertainty. In particular, UAT-GCN utilizes Monte Carlo dropout and predictive variances to estimate epistemic and aleatoric uncertainty, respectively. In addition, they also consider the recursive dependency between predictions to further improve the forecasting performance.

Intelligent Highway Adaptive Lane Learning System in Multiple ROIs of Surveillance Camera Video

M. Qiu, L. Christopher, S. Y.-P. Chien, and Y. Chen

U.S. Department of Transportation (DOT) operators commonly use adjustable surveillance cameras for traffic monitoring and desire to have an automated traffic counting system by lane. This article describes an automatic, novel, multiple-regions of interest (ROI) lane learning (MRLL) system. It detects lane centers, boundaries, and traffic directions, irrespective of zoom or direction. It finds optimal ROIs without user input by analyzing confidence scores from a chosen machine learning (ML) object detector. The MRLL optimizes lane counting performance in various real-world conditions: nighttime, extremely harsh weather, or low traffic flow conditions. Tested on 45 varied videos, it achieves an $F1$ score above 0.79 for lane center detection, 0.88 for lane boundaries, and 94% accuracy in traffic direction detection. This innovative system is currently used by the Indiana Department of Transportation for vehicle counting and flow rate estimation in real-world ITS scenarios.

Context-Aware Driver Attention Estimation Using Multi-Hierarchy Saliency Fusion With Gaze Tracking

Z. Hu, Y. Cai, Q. Li, K. Su, and C. Lv

Accurate vision-based driver attention estimation is a challenging task due to the limitations of the visual sensor, and it is a critical and fundamental function of building a human-centered intelligent driving system. Unlike previous investigations which consider it a classification task, this study newly introduces scenario contextual information to improve the accuracy and obtain a fine-grained estimation. Therefore, a data-driven hybrid architecture for context-aware driver attention estimation is proposed to jointly model the scene and state of the driver during driving. A visual saliency map is typically assumed to highlight a distinct area that can capture human attention. To leverage this characteristic, a multi-hierarchy fusion network is proposed to extract effectively saliency features of a scene image. A gaze-tracking network is employed to estimate the potential focus zone of the driver, and this coarse estimation is optimized subsequently using the extracted saliency information to obtain a fine-grained estimation. Three related and commonly used task-agnostic and task-driven datasets are adopted to evaluate the proposed saliency estimation model, and experimental results show that it can achieve state-of-the-art performance. To verify the joint modeling methodology, two new driving attention datasets supplemented with driver information are collected based on the existing ones. The results of comparative experiments indicate that the consideration of saliency features can significantly improve the estimation performance of gaze fixation, demonstrating the feasibility and efficiency of the proposed method.

Modeling, Analysis, and Control of Autonomous Mobility-on-Demand Systems: A Discrete-Time Linear Dynamical System and a Model Predictive Control Approach

A. Aalipour and A. Khani

Autonomous vehicles are rapidly evolving and will soon enable large-scale mobility-on-demand (MoD) systems applications. Managing the fleets of available vehicles, commonly known as "rebalancing," is crucial to ensure that vehicles are distributed properly to meet customer demands. This article presents an optimal control approach to optimize vehicle scheduling and rebalancing in an autonomous MoD (AMoD) system. The authors use graph theory to model a city partitioned into virtual zones. Zones represent small areas of the city where vehicles can stop and pick up/drop off customers, whereas links denote corridors of the city along which autonomous vehicles can move. They are considered vertices and edges in the graph. Vehicles employed in the AMoD scheme are autonomous, and rebalancing can be executed by dispatching available empty vehicles to areas undersupplied. Rebalancing is performed on the graph's vertices, i.e., between city areas. They propose a linear, discrete-time model of an AMoD system using a transformed network. After acquiring the model, the desired number of rebalancing vehicles for the AMoD model is derived through an optimization problem. Moreover, the well-posedness of the model is illustrated. To leverage the proposed model, they implemented the model predictive control (MPC) framework to find the optimal rebalancing and scheduling policy. They show the MPC's effectiveness and how the MPC framework can be implemented in real-time for a real-world case study. The numerical results show that the MPC with a linear cost function and linear reference, which it tracks, is effective, outperforming other MPC-based and state-of-the-art algorithms across all evaluation criteria.

CNN-Based Camera Pose Estimation and Localization of Scan Images for Aircraft Visual Inspection

X. Oh, L. Loh, S. Foong, Z. B. A. Koh, K. L. Ng, P. K. Tan, P. L. P. Toh, and U.-X. Tan

General visual inspection is a manual inspection process regularly used to detect and localize obvious damage on the exterior of commercial aircraft. Automating this typically requires estimating a camera's pose with respect to the aircraft for initialization but most existing localization methods require infrastructure, which is very challenging in uncontrolled outdoor environments, within the limited turnover time, without contact with the aircraft, or the use of UAVs. This article proposes a workflow that is infrastructure-free and easy to deploy for initialization, scan path planning, and precise localization of scan images captured from a pan-tilt-zoom camera. The authors evaluate and demonstrate the approach through experiments with real aircraft.

A Driver-Vehicle Model for ADS Scenario-Based Testing

R. Queiroz, D. Sharma, R. Caldas, K. Czarnecki, S. García, T. Berger, and P. Pelliccione

Scenario-based testing for automated driving systems (ADSs) must be able to simulate traffic scenarios that rely on interactions with other vehicles. Although many languages for high-level scenario modeling have been proposed, they lack the features to precisely and reliably control the required micro-simulation, while also supporting behavior reuse and test reproducibility for a wide range of interactive scenarios. To fill this gap between scenario design and execution, the authors propose the simulated driver-vehicle (SDV) model to represent and simulate vehicles as dynamic entities with their behavior being constrained by scenario design and goals set by testers. The model combines the driver and vehicle as a single entity. It is based on human-like driving and the mechanical limitations of real vehicles for realistic simulation. The model leverages behavior trees to express high-level behaviors in terms of lower-level maneuvers, affording multiple driving styles and reuse. Furthermore, optimization-based maneuver planners guide the simulated vehicles toward the desired behavior. The extensive evaluation shows the model's design effectiveness using NHTSA pre-crash scenarios, its motion realism in comparison to naturalistic urban traffic, and its scalability with traffic density. Finally, they show the applicability of the SDV model to test a real ADS and to identify crash scenarios, which are impractical to represent using predefined vehicle trajectories. The SDV model instances can be injected into existing simulation environments via co-simulation.

PG^{2}Net: Personalized and Group Preferences Guided Network for Next Place Prediction

B. Wang, H. Li, W. Wang, M. Wang, Y. Jin, and Y. Xu

Predicting the next destination is a key in human mobility behavior modeling. Although traditional RNN-based methods can effectively learn an individual's hidden personalized preferences for her visited places, the interactions among users can only be weakly learned through the representations of locations. Targeting this, the authors propose an end-to-end framework named personalized and group preference guided network (PG^{2}Net), which considers the users' preferences for various places at both individual and collective levels. Specifically, PG^{2}Net concatenates Bi-LSTM and attention mechanism to capture each user's long-term mobility tendency. To learn the population's group preferences, they utilize spatial and temporal information about the visitations to construct a spatial–temporal dependency module. In addition, they adopt a graph embedding method to map users' trajectories into a hidden space, capturing their sequential relation, and devise an auxiliary loss to learn the vectorial representation of her next location. The experimental results indicate the advantages of PG^{2}Net compared to the state-of-the-art baselines.

Dynamic Bird's Eye View Reconstruction of Driving Accidents

M. Boschi, L. De Luigi, S. Salti, F. Sambo, D. C. de Andrade, L. Taccari, and A. Q. Garcia

The consequences of vehicle crashes are extremely costly, especially in commercial contexts, where the loss of income due to the vehicle's unavailability while the incident is processed adds to the damage produced by the event. The shift toward connected vehicles, featuring sensors and cameras, allows to alleviate such losses by speeding up the resolution of disputes. In this article, the authors show how data collected by connected vehicles can be fused to attain automatic reconstruction of the crash dynamics, to submit a first notification of loss. They build upon state-of-the-art methods for SLAM, depth estimation, and object detection to create an animated reconstruction of the scene with the vehicles localized in space and time. The pipeline is evaluated on a benchmark of real-world videos and it can create reliable reconstructions of the moment of the impact in more than 50% of the scenes and of the overall dynamics in 37%.

A Flow-Based Centralized Route Guidance System for Traffic Congestion Mitigation

Y. Matsui and T. Yoshihiro

A new centralized architecture based on flow-based traffic management for route guidance systems is presented. By considering the capacity of detour routes and by prioritizing travel time loss among the candidate detour routes, the method improves both global traffic optimization and the benefits for each vehicle, such as travel time loss due to detours, with a limited amount of detour traffic. The evaluation results using the Osaka City map demonstrated the improved performance of this method and confirmed that the flow-based traffic management method reduces the computational load to be feasible as a centralized service.

In-Situ Dynamic Modulus Prediction for Asphalt Pavement Combining Machine Learning Algorithm and Sensing Technology

C. Zhang, S. Shen, H. Huang, and S. Yu

The in-situ dynamic modulus property of asphalt mixtures is critical to aiding the decision-making of pavement maintenance and rehabilitation. With the recent advancement in data science and sensing technologies, embedded sensors have been applied to collect the in-situ signal induced by traffic loading and estimate the traffic information. However, very limited studies have focused on evaluating the mechanical properties of pavement materials and structures using embedded sensors. This article aims to present a practical approach to performing the in-situ dynamic modulus test and develop an in-situ dynamic modulus predictive model using an artificial neural network (ANN) based on real-time sensing data. Particle-size wireless sensors were implemented in several pavement sections to collect data under vehicular loading. An empirical mode decomposition (EMD) method was introduced to calculate the intrinsic modes of the collected data as the ANN model inputs. Laboratory dynamic modulus tests using the same material as the paving projects were also performed with embedded wireless sensors. Those laboratory data, combined with the field sensing data, were used as the training and testing dataset for developing the ANN model. The results show that the developed ANN model, when adequately trained with particle-level sensing data, is feasible and robust for predicting the in-situ dynamic modulus of asphalt pavement.

A Spatiotemporal Multiscale Graph Convolutional Network for Traffic Flow Prediction

S. Cao, L. Wu, R. Zhang, D. Wu, J. Cui, and Y. Chang

Considering that information in the coarse-grained traffic graph can guide feature learning in the fine-grained traffic graph, a spatiotemporal multiscale graph convolutional network (SMGCN) that explores spatiotemporal correlations on a multiscale graph is proposed. In the proposed SMGCN, a multiscale graph is constructed, comprising a fine-grained traffic graph and a coarse-grained traffic graph. Next, road node-level correlations and functional area-level correlations are extracted from the fine-grained traffic graph and the coarse-grained traffic graph, respectively. Then, a cross-scale fusion is further designed to implement the interaction between the fine-grained traffic graph and the coarse-grained traffic graph. An adaptive dynamic graph convolution network is further developed to capture both static and dynamic spatial correlations.

Multi-Tree Compact Hierarchical Tensor Recurrent Neural Networks for Intelligent Transportation System Edge Devices

D. Liu, L. T. Yang, R. Zhao, X. Deng, C. Zhu, and Y. Ruan

Long–short-term memory (LSTM) can efficiently capture the features of time-series characteristic data and is widely used for intelligent tasks. However, the input data of some tasks have high dimensional characteristics, resulting in the number of parameters and computational complexity of LSTM models being too large, making it difficult to deploy on resource-constrained edge devices. To overcome this problem, the parameters of the LSTM model are compressed using the proposed multi-tree compact hierarchical tensor representation-dtensor block decomposition (DBD). The authors evaluate the performance of dtensor block-LSTM (DB-LSTM) and improved DB-LSTM (IDB-LSTM) models on multiple datasets and compare them with the current state-of-the-art LSTM compression models. The experimental results demonstrate that DB-LSTM and IDB-LSTM can massively compress the number of parameters of the models and shorten the training time of the models without degrading the accuracy of the models. In addition, DB-LSTM and IDB-LSTM models have better performance compared with other models.

PedCross: Pedestrian Crossing Prediction for Auto-Driving Bus

K. Kitchat, Y.-L. Chiu, Y.-C. Lin, M.-T. Sun, T. Wada, K. Sakai, W.-S. Ku, S.-C. Wu, A. A.-K. Jeng, and C.-H. Liu

PedCross, a novel framework designed to improve pedestrian crossing predictions for autonomous vehicles, utilizes pedestrian images and tracking data. The skeleton module identifies human skeletons, which are then analyzed by either random forest or LSTM models to predict movements. PedCross optimizes GPU efficiency with a skip frame method and enhances prediction accuracy by analyzing head orientation and establishing warning/dangerous zones based on pedestrian positioning. Evaluated using the JAAD and ITRI datasets, along with real-world tests on an autonomous bus, PedCross is assessed for accuracy, false positive rate, false negative rate, and compliance with ITRI standards. Findings reveal that the LSTM model demonstrates superior predictive performance over the random forest, with PedCross significantly outperforming ITRI's baseline model, free space, in real-world applications.

FlipNet: An Attention-Enhanced Hierarchical Feature Flip Fusion Network for Lane Detection

Y. Wen, Y. Yin, and H. Ran

Since lane line provides valuable information on drivable locations for autonomous driving systems, this article presents a novel segmentation-based lane detection neural network to enhance detection accuracy in complex scenarios like severe occlusion, discontinuous lane appearance, and illumination variation. A hierarchical feature flip fusion module is developed to aggregate spatial information efficiently by adopting a two-way message-passing scheme. A double-layer attention enhancement mechanism with dual-pooling coordinate attention is then proposed to enhance the subtle lane features by utilizing positional information and suppressing noise in the background. The extensive experimental results on CULane, Tusimple, and LLAMAS benchmarks demonstrate the performance and utility of the proposed method.

Distributed Robust Model Predictive Control for Virtual Coupling Under Structural and External Uncertainty

J. Li, D. Tian, J. Zhou, X. Duan, Z. Sheng, D. Zhao, and D. Cao

Virtual coupling is expected to primarily improve the capacity of a railway system. Virtual coupled systems are affected by multi-source disturbances due to the complex operating environment. However, existing research only partially considers the effects of structural or external disturbances, which limits the stability and robustness of the virtually coupled train set (VCTS). In this article, the authors aim to tackle the challenges arising from both structural and external disturbances in virtual coupling. They specifically propose a distributed robust model predictive control (DRMPC) solution based on a linearized model by joining linear feedback and feedforward control into a model predictive control (MPC) framework with a discrete Kalman filter (DKF). They also theoretically derive and prove a set of sufficient conditions for both local and string stabilities under structural uncertainty. The stability conditions are incorporated into the constraint space of the distributed MPC framework in order to guarantee system stability in the presence of structural and external uncertainties. The simulation results validate that the proposed control method can stabilize train platooning under both structural and external disturbances. The control method particularly reduces the spacing and velocity tracking errors by approximately 97.55% and 99.97% on average, respectively, as compared to several baselines.

Uncertainty Quantification of Spatiotemporal Travel Demand With Probabilistic Graph Neural Networks

Q. Wang, S. Wang, D. Zhuang, H. Koutsopoulos, and J. Zhao

This study proposes a framework of probabilistic graph neural networks (Prob-GNNs) to quantify the spatiotemporal uncertainty of travel demand, highlighting the importance of incorporating randomness into deep learning for spatiotemporal ridership prediction. This Prob-GNN framework is substantiated by deterministic and probabilistic assumptions, and empirically applied to the task of predicting the transit and ridesharing demand in Chicago across multiple time periods. The probabilistic assumptions (e.g., distribution tail and support) have a greater impact on uncertainty prediction than the deterministic ones (e.g., neural network modules and depth). Prob-GNNs can successfully predict the ridership uncertainty under significant domain shifts and can reveal the spatiotemporal pattern with uncertainty.

3D-SeqMOS: A Novel Sequential 3D Moving Object Segmentation in Autonomous Driving

Y. Zhuang, Q. Li, Y. Chen, J. Huai, M. Li, T. Ma, Y. Tang, and X. Liang

For the SLAM system in robotics and autonomous driving, the accuracy of front-end odometry and back-end loop-closure detection determine the whole intelligent system performance. However, the LiDAR-SLAM could be disturbed by current scene moving objects, resulting in drift errors and even loop-closure failure. Thus, the ability to detect and segment moving objects is essential for high-precision positioning and building a consistent map. In this article, the authors address the problem of moving object segmentation from 3D LiDAR scans to improve the odometry and loop-closure accuracy of SLAM. They propose a novel 3-D sequential moving-object-segmentation (3D-SeqMOS) method that can accurately segment the scene into moving and static objects, such as moving and static cars. Different from the existing projected-image method, they process the raw 3-D point cloud and build a 3-D convolution neural network for the MOS task. In addition, to make full use of the spatio-temporal information of the point cloud, they propose a point cloud residual mechanism using the spatial features of the current scan and the temporal features of previous residual scans. Besides, they build a complete SLAM framework to verify the effectiveness and accuracy of 3D-SeqMOS. Experiments on the SemanticKITTI dataset show that the proposed 3D-SeqMOS method can effectively detect moving objects and improve the accuracy of LiDAR odometry and loop-closure detection. The test results show the 3D-SeqMOS outperforms the existing state-of-the-art methods. They extended the proposed method to the SemanticKITTI: moving object segmentation competition and achieved third in the leaderboard, showing its effectiveness.

PCSGAN: A Perceptual Constrained Generative Model for Railway Defect Sample Expansion From a Single Image

S. He, Z. Jian, S. Liu, J. Liu, Y. Fang, and J. Hu

A GAN uses a pyramidal structure to learn the internal features of a single image. Proposed a masking and a perceptual reconstruction loss mechanism to impose specific positional and structural constraints on the images. The experiment results show that compared to other single image generation models, the images generated by this method take into account railway prior knowledge, generate railway structures that satisfy the constraints imposed by railway infrastructure designs, and also provide new information. High image realism and the lowest single-image FID were obtained.

Deep Hybrid Attention Framework for Road Crash Emergency Response Management

M. T. Kashifi

This research introduces a crash emergency response management framework, facilitating rapid medical aid to crash sites by leveraging basic crash information. A deep hybrid attention network (DHAN) is engineered to detect temporal dependencies and spatial complexities, enabling dynamic severity prediction. This model requires only the approximate location and time of the crash to determine the need for emergency response to the crash sites. Tested rigorously on a seven-year French road crash dataset (2011–2017), DHAN showcased reasonable performance with an AUC of 0.820, accuracy of 0.761, recall of 0.803, and a false alarm rate of 0.258, surpassing conventional models like deep neural network, random forest, and logistic regression.

Path-Based Origin-Destination Matrix Estimation Utilizing Macroscopic Traffic Dynamics

Y. Englezou, S. Timotheou, and C. G. Panayiotou

Efficient estimation of origin-destination (OD) matrices enables practitioners to better plan and manage the network, as well as researchers to validate novel monitoring and control methodologies. It has received significant attention over the past decades and remains one of the most challenging problems in the field of transportation. Traditional methods typically use average link counts to compute the OD demand. To the best of our knowledge, this is the first work that proposes the use of fine-grained traffic measurements for the static OD matrix estimation. The authors introduce a path-based cell transmission model whose dynamics are integrated into a mathematical program to associate OD demands with link counts. They develop custom solution methodologies for free-flow and congested conditions based on convex and nonconvex optimization theory. Utilization of detailed traffic dynamics and fine-grained measurements can pave the way to achieving a step-change improvement in OD matrix estimation through wide-area, high-resolution traffic monitoring.

Safety-Driven and Localization Uncertainty-Driven Perception-Aware Trajectory Planning for Quadrotor Unmanned Aerial Vehicles

G. Sun, X. Zhang, Y. Liu, X. Zhang, and Y. Zhuang

Recent advances in trajectory planning have enabled quadrotor unmanned aerial vehicles (UAVs) to navigate autonomously in complex environments. However, most of the existing methods do not consider the perception of quality and safety simultaneously. This article proposes a perception-aware trajectory planning strategy for quadrotors, which can ensure safety and localization accuracy. In contrast to the existing methods, the main idea of the proposed method lies in that the yaw angle trajectory is planned to actively obtain more information in the environment to improve the localization accuracy and keep the safe flight simultaneously. Following the mainstream two-stage motion planning framework, a coarse-to-fine graph search strategy is proposed to search for a safe and perception-aware yaw angle path in the first stage. Specifically, a yaw safety corridor (YSC) is proposed to guarantee safety, which can observe the obstacles directly along the tangent direction of the position trajectory. In addition, a dedicated map fisher information field (FIF) is employed to evaluate the perception quality. In the second stage, a path-guided optimization method is proposed to quickly generate a safe and perception-aware trajectory. Finally, comparative simulation and real-world experiments are conducted to verify the superior performance in terms of the perception quality and the safety of the proposed method.

Learning Semantic Behavior for Human Mobility Trajectory Recovery

W. Long, Z. Xiao, H. Jiang, Y. Xiong, Z. Qin, Y. Li, and S. Dustdar

Trajectory recovery is beneficial for various applications by reconstructing high-quality human movement trajectories. Existing approaches capture spatial–temporal transition regularities in historical trajectory for data recovery. Although promising, existing solutions suffer from two limitations. 1) They fail to recover occasionally-visited points due to the lack of semantic information when learning spatial–temporal transition regularities. 2) The information before and after missing data is not fully utilized. To overcome the limitations, the authors propose a novel semantic-aware trajectory recovery framework. First, they leverage heterogeneous information networks to encode various semantic correlations for obtaining rich semantic embeddings, which are fused with temporal information to form spatial–temporal semantic context. Then, they develop a behavior attention mechanism to capture semantic behavior transition regularities based on the bidirectional spatial–temporal semantic context. Extensive experiments on four real-world datasets show that the proposed framework outperforms the state-of-the-arts by 7%–11% in terms of recall, $F1$-score, and mean average precision.

Efficient Distributed Authentication for Intelligent Transportation Systems Using Mobile Devices

A. Alshaeri and M. Younis

DAITS is a novel approach for distributed, cost-efficient, and privacy-aware authentication and message verification for ITS. It utilizes the availability of driver's mobile devices to be leveraged as authenticators for the messages broadcasted by vehicles. Hence, the authentication of data origin and integrity verification is offered to the resource-constrained ITS nodes by the mobile devices in an as-a-service fashion. Furthermore, DAITS is a certificateless model, which deploys private smart contracts in a permissioned blockchain, for certifying nodes. The simulation results demonstrate that DAITS is both resource-efficient and scalable, and outperforms competing schemes in terms of computation and communication overhead, and verification delay.

Connected Vehicle Data-Driven Fixed-Time Traffic Signal Control Considering Cyclic Time-Dependent Vehicle Arrivals Based on Cumulative Flow Diagram

C. Tan, Y. Cao, X. Ban, and K. Tang

Fixed-time control is a widely adopted and cost-effective method for signalized intersections. However, existing studies utilizing connected vehicle (CV) data have not effectively addressed fixed-time control due to their reliance on specific vehicle arrival assumptions. To overcome this limitation, this study presents a novel traffic control approach for fixed-time signalized intersections based on a cumulative flow diagram (CFD) framework. The proposed method comprises a CFD model and a multi-objective optimization model. The CFD model establishes analytical relationships between traffic flow operations and varying signal timing parameters, with intersection demand estimated using a novel weighted maximum likelihood estimation method. A multi-objective optimization model based on CFD is formulated to minimize exceeded queue dissipation time as the primary objective and average delay as the secondary objective, which is applicable under both undersaturated and oversaturated traffic conditions. Leveraging the data-driven nature of the CFD model, a specially designed bi-level particle swarm optimization-based algorithm is employed to determine optimal cycle length (and offset if applicable) and green ratios separately. The evaluation results demonstrate that the proposed method outperforms synchro, a conventional approach, in terms of average delay and queue under various traffic conditions. Moreover, the proposed method exhibits the capability to handle specialized scenarios involving spillbacks.

A Flexible Cooperative MARL Method for Efficient Passage of an Emergency CAV in Mixed Traffic

Z. Li, Q. Wang, J. Wang, and Z. He

Connected and autonomous vehicles offer the possibility to carry out control strategies, thus having great potential to improve traffic efficiency and road safety. The efficient passage of an emergency vehicle calls for collaborative driving decision-making among multiple vehicles in a dynamically changing local area. However, existing work fails to efficiently adapt to dynamic and complex traffic conditions, thus cannot well solve the task. For a better solution, the authors propose a flexible cooperative multi-agent reinforcement learning approach based on value function factorization, called Q-LSTM. Since the traffic environment is partially observable, the centralized training and decentralized execution paradigm is adopted to learn effective cooperative strategies for individual agents. To flexibly adapt to the changing neighborhood conditions around the emergency vehicle, they introduce a long short-term memory network to decompose the learned global value function into the local value function of each agent within the neighborhood, whose quantity and entities vary over time. To address the credit assignment problem and realize the different roles of the emergency and regular vehicles, the reward mechanism and the way agent-wise Q-networks update are well-designed. Extensive experiments are conducted on the Simulation of Urban MObility platform. The results show that the Q-LSTM outperforms state-of-the-art value-based MARL methods. Moreover, the robustness and adaptability of the Q-LSTM are verified in the cases of increased traffic density.

Evaluation of Automated Driving System Safety Metrics With Logged Vehicle Trajectory Data

X. Yan, S. Feng, D. J. LeBlanc, C. Flannagan, and H. X. Liu

Real-time safety metrics are crucial for assessing risks and guiding decision-making in automated driving systems. As different behavioral assumptions are adopted in different metrics, it is difficult to evaluate and compare their performance. To overcome this challenge, this study proposes an evaluation framework utilizing logged vehicle trajectory data so that vehicle trajectories for both the subject vehicle and background vehicles are obtained and the prediction errors caused by behavioral assumptions can be eliminated. By analyzing trajectory data from a vast array of trips, the framework enables a systematic assessment of the statistical performance of different safety metrics. This proposed framework serves as a tool for researchers to refine safety metrics and aids practitioners and regulators in identifying and selecting appropriate metrics for different applications.

Intersection Is Also Needed: A Novel LiDAR-Based Road Intersection Dataset and Detection Method

Z. Li, Y. Cui, and Z. Fang

A novel LiDAR-based road intersection dataset, named the KITTI-Intersection dataset, is proposed and expected to establish a fair benchmark for 3-D intersection detection. The new dataset includes 4718 frames with 5178 instances belonging to forkroad and crossroad, respectively. Then, two LiDAR-based detection methods, called MInsectDet and MMInsectDet, are presented to solve the intersection detection issue. Specifically, MInsectDet uses a lightweight BEV backbone to alleviate the influence of numerous foreground objects at the intersection and obtain discriminative features. Then, in order to adapt to various appearances and sizes of intersection, MInsectDet is equipped with a class-aware multihead to classify and regress different categories with specific heads. For MMInsectDet, to obtain a complete intersection feature, it adopts a multi-representation backbone that integrates the BEV and voxel features. Finally, the experiments show that the methods achieve the best detection precision and maintain real-time performance on the KITTI-Intersection dataset.

A Real-Time Energy Management Strategy of Flexible Smart Traction Power Supply System Based on Deep Q-Learning

Y. Ying, Z. Tian, M. Wu, Q. Liu, and P. Tricoli

This article proposes a real-time energy management strategy (REMS) which is based on real-time information to address the problem of planning deviation of day-ahead energy management strategy (DAEMS) of the flexible smart traction power supply system (FSTPSS) which caused by the real-time fluctuation of uncertain loads or sources. The strategy is implemented by LSTM and deep Q-learning, where LSTM predicts uncertain loads or sources, and deep Q-learning controls the operation of FSTPSS based on real-time predicted state. The proposed strategy is validated with the power flow simulation model of TPSS and the real measured data. The simulation results verify the necessity and superiority of the proposed method.

End-to-End Traffic Flow Rate Estimation From MPEG4 Compressed Video Streams

B. Deguerre, C. Chatelain, and G. Gasso

Automatic traffic surveillance usually relies on the estimation of traffic flow parameters through either dedicated sensors or the processing of road surveillance cameras. However, dedicated sensors are expensive to deploy and maintain. Moreover, available video processing algorithms usually require a complex multi-step pipeline, unsuited for large-scale deployment. Herein, the authors address the problem of automatically estimating the flow rate (number of vehicles/unit of time) from surveillance cameras at low computation cost. To do so, they rely on end-to-end deep architectures applied to compressed MPEG4 part-2 video streams issued from road surveillance cameras. By leveraging the approximate flow representation induced by the compression, they heavily reduce the computation and memory requirements. They propose three end-to-end deep architectures using this coarse pixel flow representation as input. They also release two datasets, one based on synthetic videos and one collected on industrial tunnel cameras. By training the deep models on the newly introduced datasets, they evidence the effectiveness of predicting the flow rate directly from MPEG4 part-2 compressed video streams. They demonstrate an improved accuracy in comparison with a more classical RGB-based architecture and show an impressive speed up of 2065 at prediction time.

Wavelet Integrated CNN With Dynamic Frequency Aggregation for High-Speed Train Wheel Wear Prediction

H. Wang, Y.-F. Li, and T. Men

The wheel wear status of high-speed trains (HSTs) is an essential indicator of their safety and reliability. However, due to the time-varying operating state of HSTs, noisy and complex non-stationary signals are collected. This makes it difficult for data-driven algorithms to learn valuable discriminative features from data. Therefore, this inspired us to introduce signal analysis methods with clear physical meaning to improve the interpretability and performance of prediction models. This article proposes a novel multi-layer wavelet integrated convolutional neural network (MWI-Net) for predicting HST wheel-wear. Specifically, discrete wavelet transform (DWT) extends the feature learning space of CNN from the time domain to the wavelet domain, thereby capturing the frequency features that are difficult to learn in the time domain. As a remarkable information space, the DWT can effectively alleviate the frequency aliasing problem, enabling MWI-Net to distinguish valuable frequency information from complex signals. In particular, the proposed dynamic frequency aggregation mechanism endows MWI-Net with excellent frequency analysis and feature selection capabilities. Experiments on the real operation dataset of CRH1A HSTs show that MWI-Net accurately predicts the wheel wear curves, which is more competitive than existing deep learning methods. Furthermore, the authors demonstrate the feature learning mechanism inside MWI-Net through visual analysis and illustrate how it optimizes and extracts valuable features layer by layer.

A Distributed Abstract MAC Layer for Cooperative Learning on Internet of Vehicles

Y. Zou, Z. Zhang, C. Zhang, Y. Zheng, D. Yu, and J. Yu

This article focuses on enhancing reliable communications on the Internet of Vehicles for cooperative learning, where extensive user and service data is processed. Unlike prior studies that presumed reliable vehicle communications without detailing their achievement in such networks, this work pioneers in applying a distributed deep reinforcement learning scheme to develop an abstract MAC layer tailored for these needs. This innovative layer ensures successful message broadcasting among vehicles and guarantees the reception of at least one message from neighbors, thereby enabling efficient model exchanges for cooperative learning. The simulation outcomes demonstrate the effectiveness and fairness of this approach in facilitating reliable communications within the context of the Internet of Vehicles.

Modeling and Simulation of Driving Risk Pulse Field and Its Application in Car Following Model

Y. Zhang, B. Shuai, R. Zhang, C. Fan, and W. Huang

In this article, the authors use risk pulse energy to measure the threat capability of traffic factors and establish a driving risk pulse field. Combine the driving risk pulse field with the GM model to establish a car following model based on the driving risk pulse field. The simulation analysis results show that the model has the following advantages: 1) it can take into account the impact of changes in the motion state of the front and rear vehicles on the current vehicle driving. 2) Able to adjust vehicle spacing based on changes in risk energy of front and rear vehicles. 3) Able to choose appropriate driving strategies based on the risk pulse energy level of the front and rear vehicles. 4) It can achieve visualization of driving environment risks, facilitating the adoption of appropriate and reasonable driving measures.

An Integrated Vision-Based Perception and Control for Lane Keeping of Autonomous Vehicles

T. Getahun and A. Karimoddini

This article proposes a vision-based control method for autonomous vehicle lanekeeping. The proposed method consists of a robust lane detection algorithm to generate a reference path of the vehicle and a model predictive controller (MPC) for tracking the reference path. The lane detector extracts lane markings from image frames to determine ego-lane boundaries from which the lane center is calculated in the vehicle's coordinate frame. The MPC uses a kinematic vehicle model to generate the lateral and longitudinal control values necessary for smoothly tracking the reference path. The experimental results show that the proposed vision-based lane detection method performs well under various challenging road conditions such as shadows, road texture variations, interference from other road signs, and missing lane boundaries.

Risk Assessment Through Big Data: An Autonomous Fuzzy Decision Support System

M. Siami, M. Naderpour, F. Ramezani, and J. Lu

Introducing AFDSS: an autonomous fuzzy decision support system revolutionizing risk assessment in the era of big data. Utilizing advanced AI, unsupervised learning, and fuzzy logic, it autonomously analyzes uncertain, unlabeled data to evaluate risks and predict future events. Tested with real-world insurance data, AFDSS demonstrates consistent performance across diverse scenarios. Its adaptability shines through in sensitivity analysis, affirming its reliability and versatility. Say goodbye to uncertainty in decision-making with AFDSS! #AI #BigData #RiskAssessment.

d-CACC for Vehicle Platoons Lacking Acceleration Signal

M. P. S. de Abreu, F. S. S. de Oliveira, and F. de O. Souza

This article introduces an innovative approach to cooperative adaptive cruise control (CACC) named d-CACC, which overcomes wireless communication failures by employing a derivative approximation to estimate the preceding vehicle's acceleration. Unlike conventional CACC, which relies on vehicle-to-vehicle communication, d-CACC provides robustness against communication disruptions while maintaining accuracy in following the lead vehicle. Advantages include easy implementation without the need for additional algorithms for acceleration estimation, and the consideration of estimation error in the control design to mitigate unpredictable errors. Stability analysis through frequency domain methods validates the effectiveness of d-CACC, further demonstrated by simulations that illustrate its performance under real-world implementation conditions.

A Sigmoid-Based Car-Following Model to Improve Acceleration Stability in Traffic Oscillation and Following Failure in Free Flow

X. Chen, W. Zhang, H. Bai, R. Jiang, H. Ding, and L. Wei

This study introduces the sigmoid-IDM, an intelligent driving model that mitigates traffic oscillation acceleration and improves free-flow following. It employs a Sigmoid function to refine start-following characteristics and stabilize velocity, incorporating a cautious distance, driving factor, and segmentation function for enhanced asymmetry. Validated through stability analyses and simulations, the sigmoid-IDM surpasses the IDM, reducing acceleration errors by up to 28.57% and enhancing comfort and performance in various traffic scenarios.

DAIR-V2XReid: A New Real-World Vehicle-Infrastructure Cooperative Re-ID Dataset and Cross-Shot Feature Aggregation Network Perception Method

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

As an emerging research field, vehicle re-identification (Re-ID) can realize identity search between the vehicles, which plays an important role in the over-the-horizon perception of vehicle-infrastructure cooperative autonomous driving (VICAD). At present, due to the lack of data sets, the relevant research on vehicle-infrastructure cooperative (VIC) Re-ID can only be evaluated in the cross-view monitoring test set which leads to the lack of persuasion of the research. Therefore, based on the DAID-V2X dataset of Tsinghua University, this article constructs a VIC Re-ID dataset "DAIR-V2XReid" from real vehicle scenarios through vehicle-road end target tag association, thereby making it better applicable to the research of VIC Re-ID. Owing to different task scenarios, existing algorithms trained on monitoring test sets are unable to effectively complete the Re-ID task in this new dataset. Therefore, a cross-shot feature aggregation network (CFA-Net) is also proposed in this article, to tackle the case where a vehicle becomes unrecognizable due to a large change in its visual appearance across different cameras. First, the authors put forward a camera embedding module and add it to the backbone, to group different cameras and solve the problem of cross-shot perspective mutation. Second, in order to address the situation where background and vehicle division are not distinguishable, they propose a cross-stage feature fusion module, which integrates low-order semantics with high-order semantics. Finally, they use a multi-directional attention network to achieve the final feature extraction. The experimental results show that the proposed CFA-Net method achieves new state-of-the-art in DAIR-V2XReid, with mAP of 58.47%.

Minimum Distance and Minimum Time Optimal Path Planning With Bioinspired Machine Learning Algorithms for Faulty Unmanned Air Vehicles

O. Tutsoy, D. Asadi, K. Ahmadi, S. Y. Nabavi-Chashmi, and J. Iqbal

Unmanned air vehicles operate in highly dynamic and unknown environments where they can encounter unexpected and unseen failures. In the presence of emergencies, autonomous unmanned air vehicles should be able to land at a minimum distance or minimum time. Impaired unmanned air vehicles define actuator failures and this impairment changes their unstable and uncertain dynamics; henceforth, path planning algorithms must be adaptive and model-free. In addition, path planning optimization problems must consider the unavoidable actuator saturations and kinematic and dynamic constraints for successful real-time applications. Therefore, this article develops 3-D path-planning algorithms for quadrotors with parametric uncertainties and various constraints. In this respect, this article constructs a multi-dimensional particle swarm optimization and a multi-dimensional genetic algorithm to plan paths for translational, rotational, and Euler angles and generate the corresponding control signals. The algorithms are assessed and compared both in the simulation and experimental environments. The results show that the multi-dimensional genetic algorithm produces shorter minimum distance and minimum time paths under the constraints. The real-time experiments prove that the quadrotor exactly follows the produced path utilizing the available maximum rotor speeds.

Robust LPV Fault Diagnosis Using the Set-Based Approach for Autonomous Ground Vehicles

S. Zhang, V. Puig, and S. Ifqir

A robust fault diagnosis method is proposed for autonomous ground vehicles modeled as a linear parameter varying (LPV) system with bounded uncertainties. The proposed approach combines the zonotope-based set-membership approach (SMA) and the set invariance approach (SIA). First, an online fault detection strategy based on zonotopic set-membership state estimation is introduced, where the optimal observer gain is calculated offline by solving LMI optimization problems. To characterize the minimum detectable fault (MDF) and minimum isolable fault (MIF), the invariant residual sets are first obtained for the system operated in healthy and faulty modes. The proposed method relies on the propagation of the zonotopic state estimation error in a steady state based on SIA. Then, MDF and MIF are characterized for several types of faults by solving optimization problems subject to set separation conditions. Finally, experiment validations using a prototype vehicle are performed to illustrate the effectiveness of the proposed approach.

Parking Guidance and Geofencing for Last-Mile Delivery Operations

M. D. Simoni

The current shortage of road and parking capacity to accommodate freight traffic poses a significant challenge in cities. This study develops and analyzes alternative traffic management strategies for last-mile delivery operations. Three alternative implementations of parking guidance involving allocating commercial vehicles to dedicated loading/unloading bays are investigated alongside a vehicle-specific geofence strategy. Methodologically, an agent-based model framework is employed to reproduce the interactions among (parking and cruising) carriers, the surrounding traffic, and a traffic controller. An efficient metaheuristic is integrated with simulation to address the corresponding optimization. The effectiveness of the strategies in reducing traffic congestion and other externalities varies depending on the level and configuration of freight demand. Among the parking guidance strategies, those weighing more on carriers' convenience mitigate potential risks of equity and acceptability issues but at the cost of an efficiency loss. Geofencing is less problematic due to the minor operational modifications, offering comparable traffic performance improvement for low and medium demand levels.

A Vehicle Matching Algorithm by Maximizing Travel Time Probability Based on Automatic License Plate Recognition Data

C. He, D. Wang, Z. Cai, J. Zeng, and F. Fu

Vehicle re-identification aims to match and identify the same vehicle crossing multiple surveillance cameras and obtain traffic information such as travel time. To address the license plate recognition errors and unrecognized issues in vehicle re-identification based on automatic license plate recognition (ALPR) data, this article proposes a vehicle matching algorithm designed to maximize the travel time probability, including modules travel time distribution estimation, travel time probability and confidence intervals, matching time window size selection, restricted fuzzy matching, and vehicle matching optimization. The evaluation results indicate that the proposed model outperforms benchmark algorithms in four scenarios: sunny day, sunny night, rainy day, and rainy night, demonstrating its superior performance.

Visual-Based Moving Target Tracking With Solar-Powered Fixed-Wing UAV: A New Learning-Based Approach

S. Hu, X. Yuan, W. Ni, X. Wang, and A. Jamalipour

A new deep reinforcement learning (DRL)-based online control scheme is proposed for visual-based UAV-on-UAV tracking and monitoring. A DDPG-based model is designed to cope with the continuous state and action spaces of the monitor and learn the optimal acceleration control policy adapting to the solar power availability and the target's movement. Experiments show that the new algorithm can maintain a desired distance from the target, and outperform control- and optimization-based alternatives in terms of energy efficiency and tracking accuracy.

Robust Predictive Control for EEG-Based Brain–Robot Teleoperation

H. Li, L. Bi, X. Li, and H. Gan

A hierarchical robust predictive control framework consisting of a two-loop control scheme is developed to enhance the performance of electroencephalography (EEG) based robotic systems and minimize the loss of control by the end-user. Online human-in-the-loop driving experiments are performed under different disturbances, and the results show that the proposed system offers advantages of safety, enhanced navigation performance, and stronger robustness over conventional direct control of EEG-based robots.

Uncertainty Quantification for Traffic Forecasting Using Deep-Ensemble-Based Spatiotemporal Graph Neural Networks

T. Mallick, J. Macfarlane, and P. Balaprakash

To bridge the critical gap in uncertainty quantification within traffic forecasting, the authors have developed a groundbreaking approach that significantly enhances the reliability and interpretability of traffic forecasts. Although spatiotemporal graph neural networks have been successful in forecasting complex traffic patterns, they fail to account for the inherent uncertainty in data and models. The method introduces an innovative deep ensemble technique through four key stages: employing a simultaneous quantile regression loss for training a spatiotemporal graph neural network to accurately model the traffic distribution; utilizing a scalable Bayesian optimization method for hyperparameter tuning; leveraging a generative model to capture the distributions of high-performing hyperparameter configurations; and finally, decomposing the data and model uncertainties derived from the model ensembles. The approach has been rigorously tested, demonstrating superior performance compared to existing methods for uncertainty quantification. This research provides a scalable and generalized framework for incorporating uncertainty quantification into predictive models.

MNAT-Net: Multi-Scale Neighborhood Aggregation Transformer Network for Point Cloud Classification and Segmentation

X. Wang and Y. Yuan

A multi-scale neighborhood aggregation transformer network (MNAT-Net) is proposed to classify complex point cloud scenes and to segment 3-D objects simultaneously. MNAT-Net captures local fine-grained features and global geometric structural information by establishing feature correlations from local feature extraction to global geometric considerations. The proposed neighborhood and global transformer layers are designed to be plug-and-play, seamlessly integrated into existing point cloud processing networks, enhancing the network's ability to explore geometric structures and deep features in irregular and non-uniform point cloud spaces. The experimental results demonstrate that MNAT-Net achieves excellent performance in challenging point cloud classification and semantic part segmentation tasks, showing values for applications in outdoor transportation scenarios.

Communication-Aware Drone Delivery Problem

C. T. Cicek, Ç. Koç, H. Gultekin, and G. Erdoğan

A new variant of the drone delivery problem which integrates communication quality requirements into last-mile delivery operations is introduced. Unlike previous studies, the new variant, communication-aware drone delivery problem (C-DDP), minimizes the total flight distance while adhering to handover and outage constraints. The study introduces a genetic algorithm (GA) for large instances and compares its performance with an off-the-shelf MIP solver. The results show equivalent performance for smaller instances, while the GA outperforms particle swarm optimization (PSO) for larger instances. It also shows that ignoring communication constraints poses operational disruption risks, but the C-DDP mitigates this risk with a modest sacrifice in flight distance, improving communication performance by up to 28.9% with a maximum 19.1% increase in flight distance on average.

A Novel Confined Attention Mechanism Driven Bi-GRU Model for Traffic Flow Prediction

N. S. Chauhan, N. Kumar, and A. Eskandarian

Traffic congestion is a pressing issue worldwide, and machine learning (ML) methods are increasingly being used in intelligent transportation systems (ITSs) to address this problem. Deep hybrid models, in particular, have emerged as an efficient solution for traffic flow prediction. Among these models, long–short-term memory (LSTM) and bidirectional LSTM (Bi-LSTM) have been widely used to capture the temporal and periodic features of traffic data. The advancements in RNNs provide an opportunity to enhance the performance of existing models. Therefore, this work proposes a BiGRU-BiGRU model with two modules to extract temporal and periodic features from traffic data. Recurrent neural networks (RNNs) have proven to perform well using attention mechanisms. However, there is a need for an attention mechanism that strictly focuses on traffic dynamics and nearby data from the prediction points. Thus, a novel confined attention mechanism is proposed and incorporated into the first module to improve the model's performance by focusing only on the recent relevant information in the traffic flow sequence. Furthermore, the external features are integrated to improve the model's prediction performance. The proposed model is evaluated on the publicly available real-world dataset and compared with several baseline state-of-the-art methods. As an outcome, the model offers a reduction in the average value of RMSE, MAE, and MAPE for all the prediction horizons, that is ranges from 5.1% to 20.4%, from 7.3% to 27.3%, and from 6.1% to 56.6%, respectively.

A Lightweight Optimal Trajectory Planning for Smart Summon in Highly Complex and Irregular Parking Lot Scenarios

B. Hua, R. Chai, X. Wang, S. Chai, J. Zhang, and Y. Xia

An innovative lightweight optimal trajectory planner is proposed, specifically tailored for the vehicle smart summon task in complex and irregular parking lot scenarios. To ascertain the homotopy class of the optimal solution, an improved adaptive A* algorithm (IAA*) is proposed to generate a guiding route, which is then used as the initial guess to warm-start the numerical solution process. To simplify the complex and redundant collision-avoidance constraints while preserving the completeness of the solution space, a novel collision-free tunnel construction method based on the concept of spatial segmentation is proposed, replacing original constraints with simpler, environment-independent within-tunnel constraints. The planner employs a lightweight iterative optimization strategy, the effectiveness and efficiency are thoroughly demonstrated through theoretical analysis, numerical simulations, and empirical experiments.

Interference Mitigation for Automotive FMCW Radar With Tensor Decomposition

Y. Wang, Y. Huang, J. Liu, R. Zhang, H. Zhang, and W. Hong

With the surge of vehicles and transportation, sensing obstacles and warning drivers to avoid accidents have become a great concern in recent years. In the current roadworthy electromagnetic environment, the number of frequency-modulated continuous wave (FMCW) millimeter-wave (MMW) automotive radars has exploded due to their unique advantages in environmental sensing. However, the frequency band of the automotive radars is limited from 77 to 81 GHz, hence the burgeoning of radars on the road is bound to cause mutual interference and jeopardize further target detection and parameter estimation. In this article, two basic schemes are considered to mitigate the mutual interference of automotive radars. First, the authors consider the sparse characteristics of the mutual interference in the 2-D time domain and employ a sparse interference extraction (SIE) method to tackle the mutual interference. Next, they further consider the low-rank property of the useful echoes across multiple channels and propose a novel 3-D tensor decomposition (TD) method to decompose the received signals into mutual interference and useful echoes. Several numerical simulations are performed to test the robustness of the proposed TD method, especially for multiple input and multiple output (MIMO) systems under complex electromagnetic circumstances. Furthermore, more experiments are implemented to demonstrate its feasibility in practical applications in comparison to multiple state-of-the-art methods.

Measuring Sociality in Driving Interaction

X. Zhao, J. Sun, and M. Wang

The virtual-game-based interaction model (VGIM) with a novel metric, the interaction preference value (IPV), is introduced to delve into the social dynamics of driving interactions. By analyzing real-world scenarios, such as unprotected left turns, the authors identified specific social behavior patterns among human drivers. This study highlights how understanding these patterns can significantly enhance autonomous vehicle navigation by enabling more human-like decision-making and coordination. The findings suggest that integrating IPV into autonomous systems could improve motion prediction and the replication of human driving behaviors, marking a step forward in developing socially aware autonomous vehicles.

Single-View 3D Object Perception Based on Vessel Generative Adversarial Network for Autonomous Ships

S. Wang, S. Qiu, Z. Sun, T.-H. Hsieh, F. Qian, and Y. Xiao

Three-dimensional object perception in maritime is a promising means to enhance the ability of autonomous navigation. However, 3-D automatic reconstruction of dynamic targets remains a challenging task in 3-D object perception systems. In this article, the authors present an innovative GAN-based deep learning neural network for 3-D ship reconstruction. The method is able to reconstruct 3-D ship models from single-view images or videos using shape prior knowledge and a vessel generative adversarial network (Vessel-GAN), which can effectively extract the ship shape features from the single-view images or videos. Furthermore, a 3-D feature network optimization model is proposed for loop optimization of 3-D ship shape perception. In order to validate the effectiveness of the proposed method, a high-resolution single-ship dataset (HSSD) was created, and the performance of the proposed method was evaluated against the existing methods. The experimental results show that the vessel segment network (VSNet) can improve the accuracy of the HSSD dataset by 2.5% in the single ship segmentation tasks. In addition, vessel-GAN was demonstrated to be able to generate multi-view ship images with an impressive FID value of 5.82. Moreover, the model can improve the accuracy of 3-D ship modeling by 8.9% on the ShapeNet dataset. This innovative approach promises to enable 3-D perception of the marine environment for autonomous ships.

Centralized Deep Reinforcement Learning Method for Dynamic Multi-Vehicle Pickup and Delivery Problem With Crowdshippers

C. Xiang, Z. Wu, J. Tu, and J. Huang

A multi-vehicle pickup and delivery problem with crowd-shippers (DMV-PDPC) is considered. Leveraging the deep reinforcement learning framework, the attention model with the centralized vehicle network (AMCVN) method is developed. Unlike traditional heuristic or existing vehicle-changing methods, AMCVN integrates a centralized vehicle network (CVN), enhancing its overall performance. The CVN monitors the state of the vehicles and selects one of the vehicles. Then, the attention-based route-generating network (RGN) determines the next node to be visited by the chosen vehicle. Instead of using a penalty term in the reward function to regulate the sequence of visits to pickup and delivery nodes, the rolling mask scheme (RMS) is implemented. The numerical experiment demonstrates that the proposed method effectively tackles the DMV-PDPC challenge, outperforming current state-of-the-art learning-based models and heuristic methods. Moreover, the method shows exceptional generalization capabilities, as evidenced by its adaptability to different numbers of tasks and vehicles.

Modified Quadratic Spacing Policy and Extended State Observer-Based Adaptive Platoon Tracking Scheme for Heterogeneous Vehicles

Y. Liu, J. An, L. Cao, and C. K. Ahn

This work focuses on tracking and controlling a distributed platoon consisting of heterogeneous vehicles with an output dead-zone and model uncertainties. The influence of the output dead zone is handled by the Nussbaum function, and the total disturbances of each channel are estimated using extended state observers (ESOs). Moreover, to remove the traditional condition of zero initial spacing errors (ISEs), a modified quadratic spacing policy (MQSP) is established, which can obtain traffic flow stability (TFS). A distributed platoon control technique is introduced based on MQSP, second-order ESOs, and a backstepping method to achieve internal and string stability. MATLAB simulation results and PRESCAN/SIMULINK co-simulation experiments testify to the effectiveness of the proposed control strategy.

Graph Matching-Based Spatiotemporal Calibration of Roadside Sensors in Cooperative Vehicle-Infrastructure Systems

C. Zhao, D. Ding, Y. Shi, Y. Ji, and Y. Du

Sensors, such as cameras, millimeter-wave radar, and LiDAR, are widely deployed in cooperative vehicle-infrastructure systems. The demand for calibration of initial installation, damage replacements, and unstable installation has risen dramatically. Traditional methods require on-site operation and road closure; thus, repeated calibration can severely affect traffic conditions and expose operational personnel to potential safety threats. As more and more autonomous vehicles (AVs) flood the roads, this article proposes an automatic calibration framework of roadside sensors by leveraging the high-precision positioning and perception data of AVs. First, the authors design a graph-based target-matching algorithm using an AV's surrounding traffic perception data to identify the AV of interest from a dataset of multiple target trajectories recorded by roadside sensors. A line search algorithm is then designed to adjust the clock delay between sensors and establish the temporal correspondence, where a Gaussian process is applied to estimate the vehicle state in continuous time. Finally, they develop a least squares optimization model to complete the final calibration with the AV positioning data. The influence of measurement noise and missed detections on the proposed calibration framework are analyzed in simulated scenarios based on a next-generation simulation (NGSIM) dataset, and the practicability is validated based on real-world data collected at Donghai Bridge, Hangzhou Bay Bridge, and DAIR-V2X dataset. It is shown that the proposed target matching algorithm can identify an AV trajectory from roadside sensor data with 20%–90% higher accuracy than baseline models, and the framework can accurately estimate the spatial and temporal parameters even with poor data quality. The mean least squares error of the trajectory alignment reaches centimeter-level accuracy.

Time-Series Anomaly Detection in Automated Vehicles Using D-CNN-LSTM Autoencoder

F. Khanmohammadi and R. Azmi

Although connected and automated vehicles (CAVs) provide many benefits to the environment and society, new challenges in terms of security, privacy, and safety have emerged due to anomalies, errors, cyber security attacks, or malicious activities that led to accidents with fatal victims. This article tackles the anomaly detection problem by introducing a novel framework in multi-sensor CAVs, which applies an efficient data preprocessing and deep learning method. Experiments demonstrate that the proposed framework improves the detection rate of anomalies successfully. Thus, it can be used as a reference to enhance the performance of anomaly detection in automated vehicles. It is worth mentioning that the proposed framework not only in the field of CAVs but also in different scientific fields can be easily applied to detect anomalies in time series data.

Bayesian Calibration of the Intelligent Driver Model

C. Zhang and L. Sun

Accurate calibration of car-following models is essential for understanding human driving behaviors and implementing high-fidelity microscopic simulations. This article proposes a Bayesian calibration technique to capture both uncertainty in the model parameters and the temporally correlated behavior discrepancy between model predictions and observed data. Specifically, this article characterizes the parameter uncertainty using a hierarchical Bayesian framework and models the temporally correlated errors using Gaussian processes. The Bayesian calibration technique is applied to the intelligent driver model (IDM), and a novel stochastic car-following model named memory-augmented IDM (MA-IDM) is developed. The simulation results based on the HighD dataset show that MA-IDM can generate more realistic driving behaviors and provide better uncertainty quantification than the traditional IDM. Experiments also highlight that taking the driving actions from the past five seconds into account can be helpful in modeling and simulating the human driver's car-following behaviors.

HWLane: HW-Transformer for Lane Detection

J. Zhao, Z. Qiu, H. Hu, and S. Sun

Lane detection in autonomous driving perception still faces many challenges in some special scenarios such as in dazzling light and crowded roads. This article designs a novel lane detection network, namely, HW-transformer, which is based on row and column multi-head self-attention. It restricts the attention only to their respective rows and columns and transfers information across rows and columns by intersection features. In this way, the attention to the visual range around the lane is greatly expanded and the communication of global information can be achieved through intersecting features. In addition, a self-attention knowledge distillation method is proposed for the transformer model, which not only helps to improve the performance of lane detection but also has universality in better learning semantic features from general images. Experiments on BDD100K, TuSimple, CULane, and VIL100 datasets demonstrate that the method outperforms the state-of-the-art segmentation-based lane detection methods.

Hierarchical Energy Management Strategy for Plug-in HEVs Based on Historical Data and Real-Time Speed Scheduling

M. Kang, S. Zhao, and Z. Chen

This article proposes a hierarchical energy management strategy for commuter PHEVs, considering historical driving data and real-time traffic information. The upper layer controller adopts an iterative learning algorithm to analyze historical driving patterns and derive a battery state-of-charge (SOC) reference on the commuter route by solving a global energy optimization problem, which is then provided to the lower layer controller. In the lower layer controller, real-time influence from preceding vehicles is considered by designing a short-term speed prediction algorithm based on the Gaussian process regression (GPR) model. Then, two MPC controllers are designed: one for speed scheduling and another for power distribution. Finally, simulation validations demonstrate the effectiveness of the proposed strategy.

Dynamic Distance-Based Pricing Scheme for High-Occupancy-Toll Lanes Along a Freeway Corridor

I. Martínez and W.-L. Jin

Single-occupancy vehicles (SOVs) are charged to use the high-occupancy-toll (HOT) lanes, while high-occupancy-vehicles (HOVs) can drive in them at no cost. The pricing scheme for HOT lanes has been extensively studied at local bottlenecks or at the network level through computationally expensive simulations. However, the HOT lane pricing study on a freeway corridor with multiple origins and destinations as well as multiple interacting bottlenecks is a challenging problem for which no analytical results are available. In this article, the authors attempt to fill the gap by proposing to study the traffic dynamics in the corridor based on the relative space paradigm. In this new paradigm, the interaction of multiple bottlenecks and trips can be captured with Vickrey's bathtub model by a simple ordinary differential equation. They consider three types of lane choice behavior and analyze their properties. Then, they propose a distance-based dynamic pricing scheme based on a linear combination of I-controllers. This closed-loop controller is independent of the model and feeds back the travel time difference between HOT lanes and general-purpose lanes. Given the mathematical tractability of the system model, they analytically study the performance of the proposed closed-loop control under constant demand and show the existence and stability of the optimal equilibrium. Finally, they verify the results with numerical simulations considering a typical peak period demand pattern. In the future, they are interested in extending this work and testing the performance of the proposed linear combination of I-controllers for other traffic flow models.

Cooperative Path Following Control in Autonomous Vehicles Graphical Games: A Data-Based Off-Policy Learning Approach

Y. Xu, Z.-G. Wu, and Y.-J. Pan

This article investigates the distributed coordination control of path tracking and Nash equilibrium seeking of unknown automated ground vehicle systems. First, a learning-based data-driven technique is proposed to identify and reconstruct the unknown system matrices. Then, an offline reinforcement learning algorithm is proposed to derive both the optimal control policy and the policy iteration solution for graphical games, and its corresponding convergence is analyzed. Besides, an online learning algorithm only relying on the online information of states and inputs is developed to achieve optimal path tracking control. As a result, the requirement of relying on the vehicle's dynamics in the traditional tracking control protocols is completely relaxed by the proposed method. The optimal distributed control policies found by the proposed algorithm satisfy the global Nash equilibrium and synchronize all tracked vehicles to the pinning vehicle. The numerical simulation results are provided to show the effectiveness of the theoretical analysis.

A Depth-Buffer-Based Lidar Model With Surface Normal Estimation

M. Kirchengast and D. Watzenig

Virtual testing and validation of autonomous systems require real-time capable sensor models to couple the system under test with the simulated environment. This article proposes a lidar modeling approach using back projection of 360-depth images for point cloud computation. Beam incident angles are derived from estimated surface normal vectors and allow for intensity calculation. Furthermore, spatial beam divergence and multiple return modes can be simulated. Using the depth buffer as a primary input source facilitates the integration with different environment simulation tools. Virtual test drive (VTD) and CARLA serve as example cases for interfacing with the developed model. An analysis of sampling errors resulting from the underlying model principles is presented. Finally, the normal vector estimation precision and the computation time are evaluated.

Online Learning Models for Vehicle Usage Prediction During COVID-19

T. Lindroth, A. Svensson, N. Åkerblom, M. Pourabdollah, and M. H. Chehreghani

This article provides a new perspective on vehicle usage prediction by introducing online learning methods for predicting the departure time and trip distance of the first drive each day. The models are evaluated on a sizeable naturalistic driving data set collected during the COVID-19 pandemic. Accurate predictions of departure times and trip distances have many uses, like e.g., for decisions regarding when and how to precondition the batteries of electric vehicles for increased energy efficiency. Furthermore, online learning is a machine learning paradigm particularly suited to in-vehicle implementation due to lower computational demands than batch learning. Finally, this work utilizes novel approaches to estimate the quality of the predictions, since accurately quantified prediction uncertainty may be used to decide which predictions should be used to make decisions, and which to discard.

MENet: Multi-Modal Mapping Enhancement Network for 3D Object Detection in Autonomous Driving

M. Liu, Y. Chen, J. Xie, Y. Zhu, Y. Zhang, L. Yao, Z. Bing, G. Zhuang, K. Huang, and J. T. Zhou

To achieve more accurate perception performance, LiDAR and cameras are gradually chosen to improve 3-D object detection simultaneously. However, the mapping relationship construction between the two modalities is far from fully explored. The authors extend the traditional one-to-one alignment relationship between LiDAR and the camera by using different mapping enhancement strategies. Specifically, for all projected points, the authors enhance the cross-modal mapping relationship by aggregating color-texture-related features and shape-contour-related features. Furthermore, a mapping pyramid is proposed to leverage the semantic representation of the image feature at different stages. Finally, a fusion module based on an attention mechanism is designed to improve the point cloud feature with the auxiliary image feature. The effectiveness of the proposed method is demonstrated based on extensive experiments, especially for categories with sparse point clouds.

I2T: From Intention Decoupling to Vehicular Trajectory Prediction Based on Prioriformer Networks

Y. Zhou, Z. Wang, N. Ning, Z. Jin, N. Lu, and X. Shen

This article proposes a novel architecture for trajectory prediction from factored intention estimation (I2T), which decouples the trajectory prediction space into a high-level space for intention estimation and a low-level space for motion prediction. A prioriformer model is designed to serve as the backbone network for I2T so that it can accurately capture the long-term dependency couplings related to the task of intention estimation or motion prediction. The prioriformer model adopts a personalized normalization strategy, a developed multi-scale fusion encoder, and an efficient non-autoregressive decoder. Experiments on three real-world motion datasets show that I2T can significantly outperform the state-of-the-art.

Progressive Critical Region Transfer for Cross-Domain Visual Object Detection

X. Wang, P. Jiang, Y. Li, M. Hu, M. Gao, D. Cao, and R. Ding

The authors propose a novel cross-domain detection framework for adapting well-trained visual object detectors to a real-world scenario. This framework is capable of progressively transferring the critical regions, first in the broad sense and next in the narrow sense. The one module, named potential foreground mining (PFM), is designed to search for the foreground regions within the whole image and transfer them across domains. The other module, named semantic-specific RoI aggregation (SRA), is used to reinforce the aggregation of RoIs across domains without caring about semantic co-occurrence. Extensive experiments on multiple benchmark datasets indicate that the framework outperforms the baselines by 19.4%, 5.0%, and 6.1% in three typical settings, including the adverse weather, camera configuration, and complicated scene adaptation, respectively.

Efficient Dual-Stream Fusion Network for Real-Time Railway Scene Understanding

Z. Cao, Y. Gao, J. Bai, Y. Qin, Y. Zheng, and L. Jia

A new railway scene understanding method is proposed and expected to help locate foreign intrusions. By improving the performance in the backbone network, feature fusion, and loss function, the proposed method gains fast speed and high accuracy. The extensive experimental results demonstrate that the proposed method outperforms the lightweight state-of-the-art algorithms with high accuracy and fast speed on railway datasets.

Multi-AAV Cooperative Path Planning Using Nonlinear Model Predictive Control With Localization Constraints

A. Manoharan, R. Sharma, and S. Baliyarasimhuni

In this article, the authors solve a joint cooperative localization and path planning problem for a group of autonomous aerial vehicles (AAVs) in GPS-denied areas using nonlinear model predictive control (NMPC). A moving horizon estimator (MHE) is used to estimate the vehicle states with the help of relative bearing information to known landmarks and other vehicles. The goal of the NMPC is to devise optimal paths for each vehicle between a given source and destination while maintaining desired localization accuracy. Estimating localization covariance in the NMPC is computationally intensive; hence, they develop an approximate analytical closed-form expression based on the relationship between covariance and path lengths to landmarks. Using this expression the computational complexity to compute NMPC commands is reduced significantly. They present numerical simulations to validate the proposed approach for different numbers of vehicles and landmark configurations. They also compare the results with EKF and RRT* based methods to show the superiority of the proposed closed-form approach.

Yolo-3DMM for Simultaneous Multiple Object Detection and Tracking in Traffic Scenarios

L. Liu, X. Song, H. Song, S. Sun, X.-F. Han, N. Akhtar, and A. Mian

Video-based multiple object tracking (MOT) is crucial for intelligent transportation, applied in tasks from traffic surveillance to autonomous driving. Traditional MOT methods track objects through a detection-based approach, associating detections across video frames. However, these methods underutilize vehicle trajectory motion characteristics, transforming the tracking problem into motion parameter estimation. In addition, MOT often relies on off-the-shelf detectors, impacting system performance. This article introduces a novel MOT method for moving vehicles, treating tracks as unified 3-D spatiotemporal trajectories. The YOLO-3D motion model network (Yolo-3DMM) simultaneously detects and tracks vehicles in an end-to-end manner, utilizing deep learning on spatiotemporal features. Evaluation of various datasets, including a newly proposed tunnel MOT dataset, demonstrates the method's effectiveness across 100 roadside traffic scenarios, achieving outstanding performance on UA-DETRAC and Omni-MOT datasets with PR-MOTA and MOTA scores of 29.40% and 69.7%.

Design, Field Evaluation, and Traffic Analysis of a Competitive Autonomous Driving Model in a Congested Environment

D. Lee, H. Seong, G. Kang, S. Han, D. H. Shim, and Y. Yoon

Recently, numerous studies have investigated cooperative traffic systems using the communication among vehicle-to-everything (V2X). Unfortunately, when multiple autonomous vehicles are deployed while exposed to communication failure, there might be a conflict of ideal conditions between various autonomous vehicles leading to an adversarial situation on the roads. In South Korea, virtual and real-world urban autonomous multi-vehicle races were held in March and November of 2021, respectively. During the competition, multiple vehicles were involved simultaneously, which required maneuvers such as overtaking low-speed vehicles, negotiating intersections, and obeying traffic laws. In this study, the authors introduce a fully autonomous driving software stack to deploy a competitive driving model, which enabled us to win the urban autonomous multi-vehicle races. They evaluate module-based systems such as navigation, perception, and planning in real and virtual environments. In addition, an analysis of traffic is performed after collecting multiple vehicle position data over communication to gain additional insight into a multi-agent autonomous driving scenario. Finally, they propose a method for analyzing traffic in order to compare the spatial distribution of multiple autonomous vehicles. They study the similarity distribution between each team's driving log data to determine the impact of competitive autonomous driving on the traffic environment. The fully autonomous software architecture, proven successful in winning urban autonomous multi-vehicle races in South Korea, is ready for deployment on urban robot taxis. The traffic analysis addresses multi-agent scenarios and resolves competitive conflicts among robot taxi companies, crucial for smart city integration and optimizing autonomous vehicle performance in complex urban settings.

Deep Learning Based Vehicle-Mounted Environmental Context Awareness via GNSS Signal

F. Zhu, K. Luo, X. Tao, and X. Zhang

This study focuses on improving the performance of context-aware models for GNSS positioning in kinematic vehicle-mounted environments. A dataset comprising over 40 000 samples, including five contexts, is created. Efficient feature selection methods are utilized, and eight alternative models are trained. The ML-LSTM model outperforms the others, achieving 92.72% accuracy and 92.94% mAP in context-separated areas, and 87.49% accuracy and 89.21% mAP in context-continuous areas. In addition, model-based transfer learning is explored to address performance degradation on different GNSS receiver types, with the all-layer transfer approach demonstrating an 18.34% improvement.

Uniform Finite Time Safe Path Tracking Control for Obstacle Avoidance of Autonomous Vehicle via Barrier Function Approach

J. Han, J. Zhang, C. He, C. Lv, H. Wei, J. Zhang, and S. Zhao

This article presents a uniform safe path-tracking control strategy that combines obstacle avoidance with path tracking via a barrier function to address the collision avoidance problem in the path-tracking task. Unlike the conventional hierarchical collision avoidance methods, the approach employs an integral heuristic barrier function that addresses obstacle avoidance planning and reference trajectory tracking problems simultaneously. This allows us to simplify the complex safe trajectory following problem into a tractable yaw angle tracking problem and then design a novel finite-time adaptive barrier function-based sliding mode controller to address input saturation and disturbance issues. The numerical simulation results and real-vehicle experiments validate the effectiveness of the method.

Formula-E Multi-Car Race Strategy Development—A Novel Approach Using Reinforcement Learning

X. Liu, A. Fotouhi, and D. Auger

Electric motorsport such as formula *E* is becoming more and more popular in recent years. Race strategy in such races can be very complex involving resource management, e.g., energy and thermal management, but more importantly multi-car interactions which could be both collaborative and competitive. Reinforcement learning has been implemented in the literature for such electric racing strategy development but only accounts for one single car. In this article, the authors proposed a new architecture iRaXL to implement reinforcement learning for such complex strategy development featuring hybrid action space, multi-car interactions, and non-zero-sum gaming. The iRaXL proves to be able to develop different strategies for individual competitors and also team-based objectives. In a bigger scope, this framework can be used to solve more generic problems with hybrid features such as zero/non-zero-sum games, discretized/continuous action space, and competition/collaboration interactions.

Non-Cooperative and Cooperative Driving Strategies at Unsignalized Intersections: A Robust Differential Game Approach

J. Huang, Z. Wu, W. Xue, D. Lin, and Y. Chen

This article explores control strategies for intelligent vehicles at unsignalized intersections, considering interaction and communication disturbances. It formulates the problem as a robust differential game, where vehicles use locally disturbed information to compute actions. Cooperative and non-cooperative models are examined, with the controlled vehicle optimizing its own cost in the non-cooperative game and coordinating with others to optimize a joint cost in the cooperative game. The study demonstrates that local optimal strategies converge to global robust Nash equilibrium in the non-cooperative game and global robust Pareto–Nash equilibrium in the cooperative game. Simulations validate the efficacy of the robust differential game, showing that vehicles, under this approach, navigate intersections more efficiently and safely than traditional discrete game methods, even in the presence of communication disturbances.

Double Domain Guided Real-Time Low-Light Image Enhancement for Ultra-High-Definition Transportation Surveillance

J. Qu, R. W. Liu, Y. Gao, Y. Guo, F. Zhu, and F.-Y. Wang

Real-time transportation surveillance is an essential part of the intelligent transportation system (ITS). However, images captured under low-light conditions often suffer poor visibility with types of degradation, such as noise interference and vague edge features. With the development of imaging devices, the quality of the visual surveillance data is continually increasing, like 2K and 4K, which have more strict requirements on the efficiency of image processing. To satisfy the requirements on both enhancement quality and computational speed, this article proposes a double domain guided real-time low-light image enhancement network (DDNet) for ultra-high-definition (UHD) transportation surveillance. Specifically, the authors design an encoder–decoder structure as the main architecture of the learning network. In particular, the enhancement processing is divided into two subtasks (i.e., color enhancement and gradient enhancement) via the proposed coarse enhancement module (CEM) and LoG-based gradient enhancement module (GEM), which are embedded in the encoder–decoder structure. It enables the network to enhance the color and edge features simultaneously. Through the decomposition and reconstruction of both color and gradient domains, the DDNet can restore the detailed feature information concealed by the darkness with better visual quality and efficiency. The evaluation experiments on standard and transportation-related datasets demonstrate that the DDNet provides superior enhancement quality and efficiency compared with state-of-the-art methods. Besides, the object detection and scene segmentation experiments indicate the practical benefits of higher-level image analysis under low-light environments in ITS. The source code is available at https://github.com/QuJX/DDNet.

Electric Vehicle Supply Equipment Day-Ahead Power Forecast Based on Deep Learning and the Attention Mechanism

S. Matrone, E. Ogliari, A. Nespoli, and S. Leva

An advanced deep learning model is developed specifically to forecast electric vehicle power load at charging stations, providing predictions 24 h in advance. This model is structured around LSTM cells organized within a sequence-to-sequence architecture. Furthermore, an investigation into integrating an attention mechanism is undertaken to potentially enhance forecasting accuracy. To validate its effectiveness, a comprehensive case study is conducted utilizing a real-world dataset of electric vehicle charging equipment available to the public. Through meticulous hyperparameter tuning, the performance of the proposed model is compared against that of other state-of-the-art deep learning models, highlighting its superiority in forecasting accuracy and reliability.

Multi-View Spatial–Temporal Graph Convolutional Network for Traffic Prediction

S. Wei, S. Feng, and H. Yang

Multi-step traffic speed prediction is a challenging issue due to the multiple spatial–temporal dependencies among roads. Some spatial dependencies, especially those formed by different traffic modes, are not fully exploited, and how to simultaneously consider spatial and temporal dependencies and effectively integrate them within a single prediction framework needs further exploration. To tackle the above issues, the authors propose a multi-view spatial–temporal graph convolutional framework MVSTG, which adequately exploits the multi-view spatial–temporal dependencies and their interactions to improve the accuracy of traffic prediction. A view-wise attention-based fusion is proposed to adaptively identify the importance of each upstream view, fuse the multi-view information, and generate integrated results for downstream views. The experiments on two real-world urban traffic datasets demonstrate the enhanced performance of the proposed framework, especially in mid-term and long-term prediction.

Autonomous Bus Docking for Optimal Ride Comfort of Standing Passengers

A. Elawad, N. Murgovski, M. Jonasson, and J. Sjöberg

This article studies the optimization of ride comfort during the maneuver of bus docking at a stop station. The authors propose an analytical comfort model that considers the coupled and nonlinear effect of acceleration and jerk levels on the comfort perceived by standing bus passengers. This is studied through offline path planning by formulating the docking problem as a nonlinear program while implementing the comfort model to minimize discomfort. Geometry constraints are imposed on several points on the vehicle contour to ensure that the bus stays within the road bounds and docking is performed safely. The offline solution is then used as a reference in a real-time control event using a Volvo 7900 autonomous bus. To gain perspective, the measurements from the field test were compared to those of a human-driven trajectory. The results indicate that only around 1.7% of bus occupants will experience discomfort with the proposed model, in comparison to 60% in a human-driven bus, while respecting road and vehicle constraints and accurately docking within an acceptable predefined distance from the curb. They also show through simulations that in comparison to the proposed model, the traditional method of quadratic penalties for comfort modeling produces higher discomfort levels and prevents some trajectories characterized by high acceleration and jerk. Such trajectories can be permitted and comfortable using the approach.

UITDE: A UAV-Assisted Intelligent True Data Evaluation Method for Ubiquitous IoT Systems in Intelligent Transportation of Smart City

Z. Chen, Z. Qu, N. Xiong, A. Liu, M. Dong, T. Wang, and S. Zhang

The emergency of intelligent transportation systems provides new methods to monitor and alleviate traffic problems by employing many Internet of Things (IoT) devices, namely, workers, to collect data. However, there are many malicious workers (or spammers) negatively impacting the system, so it is urgent to propose an effective true data evaluation method. In this article, a UAV-assisted intelligent true data evaluation (UITDE) method has been proposed to solve this problem effectively. UITDE has two main contributions. First, the authors abandon traditional algorithms that only use workers' data to obtain estimated truths and compute their trust directly. In contrast, they employ unmanned aerial vehicles (UAVs) to collect data as ground truths to test and calculate workers' trust. Second, there are some unmalicious workers who collect inaccurate data due to their aged sensing equipment, extreme weather, or other objective reasons, so they propose a data rectification algorithm to rectify their data. The results show that the proposed method outperforms the compared methods, in terms of workers' trust evaluation, utility, and accuracy.

Modeling Collision Avoidance Behavior With Zero-Speed Pedestrians

L. C. Echeverri, J.-M. Auberlet, and J.-P. Hubert

An improved collision avoidance algorithm is introduced to deal with zero-speed pedestrians in a crowd. A zero-speed pedestrian is a pedestrian who stops for a short, undefined period of time and then resumes walking later. When integrated into a crowd simulation, zero-speed pedestrians can cause blockages, particularly livelocks, as observed when using the optimal reciprocal collision avoidance (ORCA) algorithm. A livelock in a simulation is a situation where an agent is blocked but still has room to move. To deal with livelocks that occur when using ORCA, a modification of this algorithm is proposed. The algorithm successfully prevents livelocks from occurring in typical situations where they can be observed.

EEG-Based Driver Fatigue Detection Using Spatio-Temporal Fusion Network With Brain Region Partitioning Strategy

F. Hu, L. Zhang, X. Yang, and W.-A. Zhang

A multi-branch deep learning network named spatio-temporal fusion network with brain region partitioning strategy (STFN-BRPS) is proposed to decode EEG signals collected from real-world driving scenarios and is expected to improve the accuracy and robustness of driver fatigue recognition. A recurrent multi-scale convolution module and, a dynamic graph convolution module with a brain region partitioning strategy is proposed to achieve a comprehensive spatio-temporal representation of EEG signals. In addition, the study uses channel attention to dynamically learn and integrate potential correlations of spatio-temporal features. The results demonstrate that the proposed STFN-BRPS model delivers superior classification performance compared to the mainstream methods. The study establishes a benchmark for EEG-based driver fatigue detection and related deep-learning modeling work.

Knowledge Distillation for Travel Time Estimation

H. Zhang, F. Zhao, C. Wang, H. Luo, H. Xiong, and Y. Fang

Travel time estimation (TTE) is a critical component of intelligent transportation systems. To achieve efficient and accurate trajectory-based TTE, it is essential to design a streamlined model that reduces computation and memory costs. However, this is challenging as traditional deep neural networks are limited in their calculation capabilities and can be cumbersome due to the high number of model parameters. To overcome these challenges, the authors propose a novel approach to TTE, utilizing a well-designed deep neural network model called knowledge distillation for TTE (KDTTE). By implementing knowledge distillation techniques, the model's computational and memory requirements are reduced, while simultaneously improving its accuracy. The student model leverages the knowledge of the Teacher model to learn features it would not have been able to on its own, thereby enhancing the overall accuracy of the model. The approach referred to as KDTTE, was tested on two real-world datasets and showed improved accuracy compared to nine state-of-the-art baselines, demonstrating a 34.0% and 86.8% increase in accuracy on the Chengdu and Porto datasets, respectively.

A Pedestrian Trajectory Prediction Model for Right-Turn Unsignalized Intersections Based on Game Theory

W. Li, Y. Zhang, L. Li, Y. Lv, and M. Wang

This article aims to propose a pedestrian trajectory prediction model based on game theory to study pedestrian trajectories during pedestrian-vehicle interaction at unsignalized right-turn intersections. First, pedestrian-vehicle interaction scene data at unsignalized right-turn intersections are collected. Then, a novel pedestrian-vehicle game theory model is established, where its parameters are calibrated using the Nash equilibrium of a complete information static game and the probabilities of pedestrians and vehicles crossing the street. A new pedestrian-vehicle game utility matrix is embedded into the social-generative adversarial network pedestrian trajectory prediction model. The experimental results show that the proposed model is more accurate and explanatory than traditional pedestrian trajectory prediction models.

AFM3D: An Asynchronous Federated Meta-Learning Framework for Driver Distraction Detection

S. Liu, L. You, R. Zhu, B. Liu, R. Liu, H. Yu, and C. Yuen

A distributed and collaborative driver distraction detection (3-D) framework called AFM3D is proposed. To jointly address three urgent issues of 3-D, namely, data island, data heterogeneity, and straggler issues, three optimized methods, namely, federated learning, meta-learning, and the asynchronous mode, are utilized and incorporated in AFM3D. Such that, a meta-model with fast adaptability can be trained by source vehicles collaboratively and then employed to target vehicles for personalization. The designed framework can significantly boost 3-D performance in two datasets in terms of model accuracy, recall, $F1$ score, test loss, and learning speed, compared with five state-of-the-art methods.

Mitigating Bus Bunching via Hierarchical Multi-Agent Reinforcement Learning

M. Yu, T. Yang, C. Li, Y. Jin, and Y. Xu

Bus bunching is harmful to the efficiency and stability of bus transit systems, consequently delaying the arrival time of passengers and lowering the public transportation's adoption rate. Traditional solutions adjust the additional holding time of buses at certain stations to mitigate this phenomenon. These methods sacrifice the system efficiency in exchange for even headway between neighboring buses. Little work focuses on optimizing multiple strategies when a single bus line not only has a bus bay to increase bus dwell time but also owns several dedicated bus lanes to accelerate. In this work, the authors develop a hierarchical multi-agent reinforcement learning (HMARL) framework to combine these two strategies. Speeding up certain buses via dedicated lanes can counteract the negative influence of additional holding time. Next, to support the two strategies, they devise a two-layer policy scheme, one for high-level policy deciding holding or accelerating and the other for low-level policy determining the specific dwell time or increase of speed. Besides, to handle the issue that the controlling actions of agents are asynchronous and temporally extended, they establish a duration-critic module based on the recurrent neural networks (RNNs) mechanism to model other agents' impact during the period between two consecutive controls. They evaluate the proposed framework on a simulated bus line with a quasi-real-world pattern to compare the performance of both traditional headway-based control methods and existing MARL methods. The results show that the method outperforms other baselines, not only stabilizing a strongly unstable bus line but also shortening the traveling times of passengers.

Game-Theoretic Decision-Making Method and Motion Planning for Autonomous Vehicles in Overtaking

L. Cai, H. Guan, Q. H. Xu, X. Jia, and J. Zhan

Overtaking is a common driving behavior used by human drivers while driving. Therefore, the decision on overtaking is very important in the automatic driving decision. To be able to improve the passing efficiency of intelligent vehicles, it is crucial to be able to interact with oncoming vehicles with different driving styles. An overtaking decision needs to be adapted to the situation where the vehicle being overtaken is potentially stationary or moving. Therefore, this article proposes an overtaking decision method based on potential conflict areas based on the requirements. First, the planning method for each stage is given, and the generation method of the potential conflict area is proposed. Second, the interaction process between the host vehicle and the opposite oncoming vehicle is modeled by a dynamic game based on the potential conflict area. A driving style assessment method for oncoming vehicles based on potential conflict areas is proposed. Third, the priority of passing the potential conflict area of multiple oncoming vehicles is divided to correct the speed planning in the waiting and the speed payoff function in the game. Finally, the overtaking decision is simulated and validated by a virtual test drive.

Context-Aware Attention Encoder-Decoder Network for Connected Heavy-Duty Vehicle Aggressive Driving Identification Under Naturalistic Driving Conditions

K. Tang, L. Yang, Y. Ma, T. Guo, and F. He

A context-aware attention encoder–decoder deep framework is presented for heavy-duty vehicle aggressive driving identification in a connected environment. It takes multi-source heterogeneous data as inputs to capture the impact of various factors on the driving behavior of heavy-duty vehicles under naturalistic driving conditions. To encode temporal dependencies and complex patterns of driving behaviors from driving signal series, a deep encoder–decoder architecture based on BiLSTM is developed. A context-aware temporal attention mechanism is proposed to adaptively focus on the information that facilitates the learning of feature representations for driving behavior identification. By capturing temporal dynamics and driving patterns with layered feature representations in an adaptive way, aggressive driving behaviors can be accurately identified. The empirical results validate the effectiveness and robustness of the proposed model.

Secure Control Design for Cooperative Adaptive Cruise Control Under False Data Injection Attack

P. Ansari-Bonab, J. C. Holland, J. Cunningham-Rush, S. Noei, and A. Sargolzaei

Cooperative adaptive cruise control (CACC) is one of the many advanced driver assistance systems (ADASs) that leverage communication between nearby vehicles to maintain speed while ensuring safe following distances. The current CACC algorithms are designed with the assumption that the communication channel is secure. However, the use of communication channels makes CACC susceptible to attacks, such as false data injection (FDI). This article develops a novel secure nonlinear controller and a nonlinear observer that can estimate FDI attacks in real-time. Furthermore, this article shows that the developed controller and FDI attack estimation techniques ensure semi-globally uniformly bounded tracking under FDI attacks, noise, and disturbances. The efficaciousness of the proposed CACC algorithm was demonstrated in simulation and through experimental implementation. During testing using both methodologies, the controller was able to maintain a safe following distance and estimate FDI attacks and noise in real-time.

An Anonymous and Secure Data Transmission Mechanism With Trajectory Tracking for D2D Relay Communication in 3GPP 5G Networks

Y. Sun, J. Cao, X. Ren, C. Tang, B. Niu, Y. Zhang, and H. Li

A new anonymous and secure D2D data transmission scheme with trajectory tracking is presented to enhance security in D2D relay communication. With the help of the core network, the scheme constructs anonymous and secure channels among relay devices based on Chebyshev polynomials, hash-based message authentication code, and symmetric encryption. Formal verification tools and informal security analysis have been implemented to demonstrate its security features. An APP, "D2DWatchmen," is deployed to simulate the whole protocol with robustness and effectiveness.

VPL-SLAM: A Vertical Line Supported Point Line Monocular SLAM System

Q. Chen, Y. Cao, J. Hou, G. Li, S. Qiu, B. Chen, X. Xue, H. Lu, and J. Pu

The article introduces VPL-SLAM, a monocular SLAM system integrating structural vertical line constraints, demonstrating exceptional performance in challenging scenarios. It presents a novel approach to representing structural vertical lines and a streamlined mapping pipeline, effectively addressing optimization issues with map line features. Through rigorous testing on self-collected underground parking and KITTI odometry datasets, VPL-SLAM showcases notable advancements in accuracy and stability. In addition, the article delves into the efficiency and efficacy of the innovative structural vertical line mapping methodology.

Parallel Channel Estimation for RIS-Assisted Internet of Things

Z. Chen, L. Huang, S. Xia, B. Tang, M. Haardt, and X. Y. Zhang

Considering the fact that the characteristic of the reflected channel is generally different from the direct channel, the problem of parallel channel estimation is investigated for RIS-assisted IoT systems. Under the proposed framework, the two-minimization criterion is utilized to efficiently perform the direct and the reflected channel estimation, respectively. by combining the gradient descent and the alternating minimization method, a flexible and fast algorithm is developed to reduce the number of the pilot symbols. The numerical results confirm the superiority and accuracy of the proposed method, which is more suitable for RIS-assisted IoT systems.

Stochastic Model-Based Deep Learning for Constrained Optimization of IEEE 802.11 Vehicular Communication Systems

X. Ma and S. Ding

This article proposes a real-time constrained optimization platform that combines a fast stochastic model with a carefully configured regression deep learning neural network (DLNN) to achieve an optimal balance between QoS and channel spectrum efficiency. The stochastic model predicts the QoS of IEEE 802.11 broadcast vehicular ad hoc networks. Data from the stochastic model is preprocessed and used to train the DLNN for real-time optimization by accomplishing the inverse mapping. Through collaborative work, the DLNN and stochastic model identify the optimal parameter set that maximizes channel efficiency while adhering to QoS constraints quickly and precisely. The effectiveness and robustness of the proposed optimization system are demonstrated through experiments conducted on Google Colab using TensorFlow and Python, showcasing its superiority over alternative optimization algorithms.

TrajPRed: Trajectory Prediction With Region-Based Relation Learning

C. Zhou, G. AlRegib, A. Parchami, and K. Singh

Reliable trajectory forecasting needs to capture social interactions and stochastic goals. Edge-based relation modeling represents interactions using pairwise correlations from precise individual states. Nevertheless, edge-based relations are vulnerable under perturbations. The authors propose a region-based relation learning paradigm that models social interactions via the changes in the density of crowds. They show that region-based relations are less susceptible to perturbations. To capture the stochastic goals, they exploit a CVAE to realize multi-goal estimation. They integrate multi-goal estimation and region-based relation learning to model social interactions and stochastic goals in a prediction framework. The framework is evaluated on the ETH-UCY dataset and the Stanford Drone Dataset. They show that the predicted intermediate trajectory distributions better fit the ground truth when incorporating the region-wise relation module. The framework outperforms the state-of-the-art models on the

Stanford Drone Dataset by 27.61%/18.20% of ADE/FDE metrics.

The Influence of Motion-Cueing, Sound and Vibration Feedback on Driving Behavior and Experience—A Virtual Teleoperation Experiment

L. Zhao, M. Nybacka, L. Drugge, M. Rothhämel, A. Habibovic, and H. Hvitfeldt

The influence of motion-cueing, sound, and vibration feedback on driving behavior and experience is investigated. A prototype teleoperation station is developed with feedback from audio, vibration actuators, and motion cues. Using this prototype, the experiment is carried out in two scenarios. Objective and subjective assessment methods are used to evaluate driving behavior and experience separately. The results indicate that the combination of motion-cueing, sound, and vibration feedback provides the most favorable driving experience for the participants. Specifically, sound and vibration feedback enhance drivers' sense of speed, while motion-cueing feedback helps in road surface sensing, leading to increased throttle reversal rate in the low-speed disturbance scenario. However, it is noteworthy that motion-cueing feedback does not significantly improve driving performance in the dynamic driving scenario of this study.

D-SPAC: Double-Sided Preference-Aware Carpooling of Private Cars for Maximizing Passenger Utility

L. Chen, H.-N. Dai, X. Yuan, J. Huang, Y. Wu, and J. Wu

Existing carpooling schemes are not tailored for private car-based carpooling services with an oversimplified assumption that passengers pay detour fees and there is no guarantee on the passenger's travel time. Consequently, such limitations not only harm the passenger's carpooling incentive but also hurt the passenger's quality of experience as well as the driver's utility. A novel framework for the double-sided preference-aware carpooling problem is proposed to explore the driver-passenger bargaining space and to guarantee both drivers' expected utility and passengers' QoE. The proposed coalitional double auction-based algorithm and the deep reinforcement learning-based algorithm have shown advantages over three benchmarks.

VDTNet: A High-Performance Visual Network for Detecting and Tracking of Intruding Drones

X. Zhou, G. Yang, Y. Chen, L. Li, and B. M. Chen

The misuse of drones can jeopardize public safety and privacy. The detection and catching of intruding drones are crucial and urgent issues to be investigated. This article proposes a lightweight, effective, and efficient anti-drone network for visually detecting and monitoring unfriendly drones with a constrained view field flying against a complex environment. Despite only 3.5M in model size, the proposed method has achieved commendable accuracy and speed on four publicly available datasets. Furthermore, it requires minimal computational resources. The effectiveness and reliability of the proposed method have been validated through numerous simulation experiments and real-world trials including air-to-air detection and ground-to-air detection.

CARLA-GEAR: A Dataset Generator for a Systematic Evaluation of Adversarial Robustness of Deep Learning Vision Models

F. Nesti, G. Rossolini, G. D'Amico, A. Biondi, and G. Buttazzo

Adversarial examples represent a serious threat to deep neural networks in several application domains and a huge amount of work has been produced to investigate them and mitigate their effects. Nevertheless, no much work has been devoted to the generation of datasets specifically designed to evaluate the adversarial robustness of neural models. This article presents, a tool for the automatic generation of photo-realistic synthetic datasets related to driving scenarios that can be used for a systematic evaluation of the adversarial robustness of neural models against physical adversarial patches, as well as for comparing the performance of different adversarial defense/detection methods. The tool is built on the CARLA simulator, using its Python API, and allows the generation of datasets for several vision tasks in the context of autonomous driving. The adversarial patches included in the generated datasets are attached to billboards or the back of a truck and are crafted by using state-of-the-art white-box attack strategies to maximize the prediction error of the model under test. Finally, the article presents an experimental study to evaluate the performance of some defense methods against such attacks, showing how the datasets generated with might be used in future work as a benchmark for adversarial defense in the real world. All the code and datasets used in this article are available at http://carlagear.retis.santannapisa.it.

A Cognition-Inspired Human-Like Decision-Making Method for Automated Vehicles

S. Xie, Y. Yang, M. Fu, and J. Zheng

This article proposes a human-like AD decision-making method based on drivers' cognition mechanisms. The fundamental and difficult thing of this method is to figure out the drivers' cognitive mechanism systematically and comprehensively, which is still either too rough or too fragmented for AD development. By integrating the abundant studies about drivers' cognition in multiple fields, it proposes two novel conceptual models: the potential hazard model (PHM) illustrates the mechanisms of drivers' reactions in simple meta-scenarios while the candidate selection model (CSM) explains how drivers handle complicated scenarios based on PHM. Based on PHM and CSM, it designs the human-like decision-making method for AD. This method integrates cognitive mechanisms, natural driving data, optimization-based planning, and other techniques profoundly. The experiments in extensive road and traffic scenarios verify that the method shows good generalizability, interpretability, and human likeness.

Connected and Autonomous Vehicles in Web3: An Intelligence-Based Reinforcement Learning Approach

Y. Ren, R. Xie, F. R. Yu, R. Zhang, Y. Wang, Y. He, and T. Huang

This article proposes an intelligence-based reinforcement learning (IRL) approach for CAVs in Web3. The proposed method enables model transactions between CAVs. Also, the

IRL is used to solve the model trading issue. The proposed scheme shows good generalization and can auto-balance exploration and exploitation, simultaneously achieving outperforming performance on the model trading issue with no rewards.

Subjective Vertical Conflict Model With Visual Vertical: Predicting Motion Sickness on Autonomous Personal Mobility Vehicles

H. Liu, S. Inoue, and T. Wada

Passengers of level 3–5 autonomous personal mobility vehicles (APMVs) can perform non-driving tasks, increasing the risk of motion sickness, particularly during maneuvers to avoid pedestrians or obstacles. Numerous studies address this issue, developing computational motion sickness models. To model motion sickness due to conflict between visual vertical information and vestibular sensation, this study proposes an approach called the 6 DoF SVC-VV model, incorporating a visually perceived vertical block into a conventional 6 DoF SVC model to predict visual vertical directions from simulated human-like visual input. In a slalom driving experiment with 27 participants, 21 of them observed motion sickness during APMV rides, with more severe symptoms when engaging in tasks like tablet use. In contrast to the conventional 6 DoF SVC model, the proposed 6 DoF SVC-VV model effectively described increased motion sickness in scenarios with conflicting visual vertical and gravitational acceleration directions during the experiment.

Model Predictive Trajectory Optimization and Control for Autonomous Surface Vessels Considering Traffic Rules

A. Tsolakis, R. R. Negenborn, V. Reppa, and L. Ferranti

This article presents a rule-compliant trajectory optimization method for autonomous surface vessels (ASVs) using model predictive contouring control and incorporating international regulations for preventing collisions at sea (COLREGs). The algorithm formalizes traffic rules, integrates them with vessel dynamics, and plans over a long horizon. Validated through simulations, including scenarios with multiple obstacle vessels, the method ensures a proactive, rule-compliant motion planner suitable for mixed-traffic environments. Key contributions include the formal derivation of affine constraints for rule compliance, simplified transition expressions for traffic rule decision-making, and scalability for safe navigation in dense traffic conditions. The work addresses challenges in deploying ASVs in real traffic, emphasizing safety and interaction with human-operated vessels.

Exploiting Low-Level Representations for Ultra-Fast Road Segmentation

H. Zhou, F. Xue, Y. Li, S. Gong, Y. Li, and Y. Zhou

Achieving real-time accuracy on embedded platforms has always been the pursuit of road segmentation methods. To this end, they have proposed many lightweight networks. However, they ignore the fact that roads are “stuff” (background or environmental elements) rather than “things” (specific identifiable objects), which inspires us to explore the feasibility of representing roads with low-level instead of high-level features. Surprisingly, the authors find that the primary stage of mainstream network models is sufficient to represent most pixels of the road for segmentation. Motivated by this, they propose a low-level feature-dominated road segmentation network (LFD-RoadSeg). Specifically, LFD-RoadSeg employs a bilateral structure. The spatial detail branch is first designed to extract low-level feature representation for the road by the first stage of ResNet-18. To suppress textureless regions mistaken as the road in the low-level feature, the context semantic branch is then designed to extract the context feature in a fast manner. To this end, in the second branch, they asymmetrically downsample the input image and design an aggregation module to achieve comparable receptive fields to the third stage of ResNet-18 but with less time consumption. Finally, to segment the road from the low-level feature, a selective fusion module is proposed to calculate pixel-wise attention between the low-level representation and context feature, and suppress the non-road low-level response by this attention. On KITTI-Road, LFD-RoadSeg achieves a maximum $F1$-measure (MaxF) of 95.21% and an average precision of 93.71%, while reaching 238 FPS on a single TITAN Xp and 54 FPS on a Jetson TX2, all with a compact model size of just 936k parameters. The source code is available at https://github.com/zhouhuan-hust/LFD-RoadSeg.

UDTIRI: An Online Open-Source Intelligent Road Inspection Benchmark Suite

S. Guo, J. Li, Y. Feng, D. Zhou, D. Zhang, C. Chen, S. Su, X. Zhu, Q. Chen, and R. Fan

In this article, an online open-source benchmark suite was introduced, referred to as UDTIRI, within which the first intelligent road inspection (IRI) competition—road pothole detection was launched. The competition provides a large-scale, well-annotated dataset that can be used for the training and evaluation of object detection, semantic segmentation, and instance segmentation networks. The annotations for the training and validation sets are made accessible to researchers, where a comprehensive performance evaluation of their developed networks on the test set can be obtained by submitting the results through the online benchmark platform. Furthermore, the benchmark provided extensive baseline experimental results using 14 object detection networks, 30 semantic segmentation networks, and ten instance segmentation networks. The authors anticipate that this benchmark will catalyze the integration of advanced urban digital twins (UDT) techniques into IRI.

State Aggregation and Lower Bound-Based ADP Approach for Dynamic Pick-Up Routing Problem With Capacity Constraint

Y. Wu and M. Jian

The authors investigate a dynamic parcel pick-up problem with stochastic demand, stochastic service requests, and stochastic service cancellations considered simultaneously. They formulate the problem as a Markov decision process and jointly apply state aggregation and approximate dynamic programming to overcome the curse of dimensionality. They introduce the concept of $aggregation granularity$ and propose a state aggregation method that drastically reduces the size of the state searching space. They develop an ADP-based routing policy with a lower bound of the post-decision state value function being derived. Then, they apply the lower bound-based policy online within the rollout framework. The impact of $aggregation granularity$ and the advantages of the online rollout policy are examined numerically.

Short-Term Metro Origin-Destination Passenger Flow Prediction via Spatio-Temporal Dynamic Attentive Multi-Hypergraph Network

L. Shen, J. Li, Y. Chen, C. Li, X. Chen, and D.-H. Lee

Metro bears a large number of passenger flows in urban transportation systems. Short-term metro origin-destination (OD) passenger flow prediction is an essential component of intelligent transportation systems (ITSs). In this article, the authors exploit a novel data structure, hypergraph, to represent the complex correlation between OD pairs, and propose an elaborately designed spatio-temporal dynamic attentive multi-hypergraph network (ST-DAMHGN) to tackle the short-term OD passenger flow prediction problem. In the proposed framework, they construct multiple hypergraphs to model the relationship between OD pairs and adopt the perceptual field to realize efficient and effective vertex feature extraction. Then, they utilize the attention mechanism to adaptively and dynamically synthesize information from multiple hypergraphs and make a trade-off between exploration and exploitation. A case study is conducted on the metro system of Hangzhou, China. The results of extensive experiments show that ST-DAMHGN outperforms baseline models. The efficiency is validated for the multi-hypergraph model, perceptual field, spatial feature extraction, and attention mechanism.

Rethinking the Evaluation of Driver Behavior Analysis Approaches

W. Chai, J. Wang, J. Chen, S. Velipasalar, and A. Sharma

Crashes caused by distracted driving result in over 3000 deaths annually in the USA. Hence, autonomous detection of distraction is critical for driver-assist systems. While many methods have been proposed, challenges remain in proper performance evaluation, reproducibility, and industry adoption. Common issues include a lack of accessible codes, use of private datasets, and vague experiment details, sometimes leading to inflated accuracy, and not reproducible results. Moreover, performance metrics should be chosen carefully to measure various aspects, including a method's generalizability, and action localization ability in time. This study compares state-of-the-art methods by using different data splits and metrics on the StateFarm and AI CITY Challenge datasets. It highlights the importance of leave-N-driver-out cross-validation to ensure real-world applicability with never-before-seen drivers. The results demonstrate the significance of data splitting and performance metrics in the evaluation and their effects on the results.

Drivable Region Completion via a 3D LiDAR

W. Jang and E. Kim

Since the drivable region is important for an intelligent vehicle to drive, this article proposed a method to find the drivable region using a 3-D LiDAR. Since the proposed method used a completion approach, it is able to detect drivable regions even if it is occluded and not present in the point cloud.

Acoustic Non-Line-of-Sight Vehicle Approaching and Leaving Detection

M. Hao, F. Ning, K. Wang, S. Duan, Z. Wang, D. Meng, and P. Xie

An acoustic non-line-of-sight (NLOS) vehicle detection method is proposed and expected to detect the occluded vehicle at intersections early. Using spectrogram and direction of arrival (DOA) estimation results as inputs, a two-branch parallel CNN-LSTM (pCRNN) network is designed to combine acoustic NLOS vehicle detection and localization tasks. On the newly created vehicle approaching and leaving detection dataset, the experimental results show that the occluded approaching vehicle was detected 1 s before it entered the line of sight, and the approaching/leaving status was further inferred, providing detailed traffic information for the intelligent vehicles' response decisions.

Highway Visibility Level Prediction Using Geometric and Visual Features Driven Dual-Branch Fusion Network

Y. Sun, J. Tang, Q. Liu, Z. Zhang, and L. Huang

Automatic prediction of visibility from surveillance images can provide timely warnings for transportation management departments and drivers, which is of great significance for improving the driving safety of highways in foggy weather. The currently mainstream prediction models are based on deep networks, which mainly learn visual features as clues to predict visibility levels. However, the geometric features of highways, such as the lane lines that can be observed from surveillance images are also important clues to reflect the visibility. Therefore, the authors propose a dual-branch fusion network driven by both geometric and visual features to achieve robust and effective visibility prediction. Specifically, they first exploit dual branches to learn the geometric features of highways and deep visual features from the foggy surveillance images, respectively. They then design a fused classification module to fuse the dual-branch features to predict the visibility level. In order to simultaneously purify features during the fusion process, it utilizes a road attention block to highlight the deep visual features corresponding to the highway road area, and a lane length estimation block to extract the feature of the length of observable lane lines. Therefore, the dual-branch features can be adaptively fused to boost prediction performance. Meanwhile, they construct a real-scene foggy image dataset, which is all gathered from the surveillance video of real highways in China. They validate the effectiveness of the proposed network on this real-scene dataset and the synthetic dataset FRIDA. The experimental results show that the method can predict visibility levels more accurately than multiple existing methods.

Efficient Task Planning for Heterogeneous AGVs in Warehouses

Y. Li and H. Huang

The problem of task planning for heterogeneous AGVs (TPHA) is addressed. A novel framework that considers route planning and task assignment simultaneously is presented. Within this framework, several algorithms are proposed to efficiently plan routes and assign tasks to the most suitable AGVs. Extensive experiments on both real and synthesized datasets verify the effectiveness and efficiency of proposed algorithms.

Enhancing Subway Efficiency on Y-Shaped Lines: A Dynamic Scheduling Model for Virtual Coupling Train Control

C. Chen, L. Zhu, and X. Wang

A novel approach based on the virtual coupling of train control systems in subway lines has the potential to enhance transportation efficiency. Y-shaped lines have proven to be valuable in improving efficiency, and the rational application of the virtual coupling strategy on these lines can help to alleviate passenger flow pressure. However, train operations can be affected by uncertain disturbances that require real-time adjustments. Due to the complexity of train schedules on Y-shaped lines, delays may be difficult to manage if they are scheduled according to a single timetable. In this article, the authors propose a flexible adjustment of the planned schedule on Y-shaped lines, which considers the switching sequence of turnouts while ensuring safety. They present a mixed-integer programming (MIP) model that optimizes the total train delays, number of stranded passengers, and passenger waiting time. The simulation results demonstrate the model effectively improves punctuality while reducing stranded passengers and waiting time.

Progression Cognition Reinforcement Learning With Prioritized Experience for Multi-Vehicle Pursuit

X. Li, Y. Yang, Z. Yuan, Z. Wang, Q. Wang, C. Xu, L. Li, J. He, and L. Zhang

Multi-vehicle pursuit (MVP) such as autonomous police vehicles pursuing suspects is important but very challenging due to its mission and safety-critical nature. This article proposes a progression cognition reinforcement learning with prioritized experience for MVP (PEPCRL-MVP) in urban multi-intersection dynamic traffic scenes. PEPCRL-MVP uses a prioritization network to assess the transitions in the global experience replay buffer according to each reinforcement learning agent's parameters. With the personalized and prioritized experience set selected via the prioritization network, diversity is introduced to the multi-agent learning process, which can improve collaboration and task-related performance. Furthermore, PEPCRL-MVP employs an attention module to extract critical features from dynamic urban traffic environments. These features are used to develop a progression cognition method to adaptively group pursuing vehicles. Each group efficiently targets one evading vehicle. Extensive experiments conducted with a simulator over unstructured roads of an urban area show that PEPCRL-MVP is superior to other state-of-the-art methods.

Integrated Conflict Management for UAM With Strategic Demand Capacity Balancing and Learning-Based Tactical Deconfliction

S. Chen, A. D. Evans, M. Brittain, and P. Wei

The article presents an innovative framework for managing urban air mobility (UAM) traffic. It addresses the challenge of ensuring aviation safety and operational efficiency in high-density urban airspaces. This work integrated two core functions: strategic conflict management using demand capacity balancing (DCB) and tactical separation using multi-agent reinforcement learning. More importantly, this work investigated and analyzed the interdependence of these two functions: tactical deconfliction automation significantly impacts DCB's capacity limit, and DCB sets the proper traffic volume for effective tactical deconfliction. This integrated approach marks substantial steps forward in both practically managing high-density urban airspaces and fundamental research in the interactions between strategic and tactical conflict management.

Transformer-Based Reinforcement Learning for Scalable Multi-UAV Area Coverage

D. Chen, Q. Qi, Q. Fu, J. Wang, J. Liao, and Z. Han

This article introduces a transformer-based deep multi-agent reinforcement learning (T-MARL) method for the scalable multi-UAV area coverage problem (ACP). The authors utilize the transformer model, known for its ability to adapt to variable input dimensions, to extract crucial information from the complex network states. Recognizing the potential pitfalls of random initialization in transformer models, which can lead to training failure, the authors propose a baseline-assisted pre-training scheme. This innovative approach allows T-MARL to rapidly provide an initial policy model for UAVs, leveraging imitation learning. Furthermore, the temporal-difference (1) algorithm is employed to initialize policy evaluation networks. The efficacy of T-MARL is demonstrated through experimental results, which reveal that it enables UAVs to exhibit cooperative behaviors and achieve superior performance on ACP.

Learning Dynamical Position Embedding for Discriminative Segmentation Tracking

Y. Yang and X. Gu

This article proposes a discriminative segmentation tracking framework based on both cross-correlation and cross-attention, which enables the simultaneous capture of local position information and global contextual semantics. Specifically, a dynamic position embedding network using cross-correlation is presented to compensate for the position information lost in the cross-attention. Meanwhile, an attention-based feature fusion network is proposed to incorporate position-aware features with this new cross-attention module. The extensive experimental results on eight challenging tracking benchmarks show the superiority of the proposed approach.

Leveraging Driver Attention for an End-to-End Explainable Decision-Making From Frontal Images

J. Araluce, L. M. Bergasa, M. Ocaña, Á. Llamazares, and E. López-Guillén

The authors propose a model that leverages the driver's attention to obtain explainable decisions based on an attention map and the scene context. The novel architecture addresses the task of obtaining a decision and its explanation from a single RGB sequence of the driving scene ahead. They base this architecture on the transformer architecture with some efficiency tricks to use it at a reasonable frame rate. Moreover, they integrate in this proposal the previous ARAGAN model, which obtains SOTA attention maps, to improve the performance of the model thanks to understanding the sequence as a human does. They train and validate the proposal on the BDD-OIA dataset, achieving on-pair results or even better than other state-of-the-art methods. In addition, they present a simulation-based proof of concept demonstrating the model's performance as a copilot in a close-loop vehicle-to-driver interaction.

Fuel and Emissions Optimization for Connected Diesel Engine Vehicles With Hierarchical Model Predictive Control

K. Jiang, H. Zhang, and F.-Y. Wang

This article studies a hierarchical model predictive control (MPC) strategy to optimize the powertrain and after-treatment systems for connected diesel-powered vehicles. With the development of vehicle connectivity and autonomy, it is convenient to acquire vehicle speed prediction and future geographic information for improving driving safety and fuel economy. Inspired by such achievements, preview speed, and geographic information are utilized to enhance the control performance of diesel engines and urea-based selective catalytic reduction (SCR) systems simultaneously in this work. With the short-term prediction of vehicle speed and road grade, the upper-level controller for the diesel engine could respond in advance and hence reduce fuel consumption by avoiding sudden braking and acceleration. Similarly, according to the engine-out NOx emissions predicted through upper-level control actions, the lower-level dosing controller of the SCR system could remove the NOx emissions more efficiently as well. Finally, to explore the effectiveness of the designed predictive control strategy, several simulations are implemented based on the real experimental data. The comparison results demonstrate the remarkable improvements of the proposed approach.

Game-Theoretic Driver-Automation Cooperative Steering Control on Low-Adhesion Roads With Driver Neuromuscular Delay

J. Liu, H. Guo, Q. Meng, W. Shi, Z. Gao, and H. Chen

This research develops a novel driver-automation cooperative steering control methodology based on nonlinear game theory to address collision risks associated with inexperienced drivers on low-adhesion roads. Utilizing a model predictive control (MPC) driver model, it accounts for drivers' neuromuscular delay and experience deficits. A dynamic weighting strategy is developed to balance driver-automation handling conflicts and road risk factors. The control challenge is framed as a nonlinear game, leveraging piecewise affine (PWA) theory for linearization, enabling optimal control strategy development. Comparative simulations and driver-in-the-loop tests validate the approach, evidencing its effectiveness in reducing driver steering load and enhancing vehicle stability more effectively than existing cooperative steering approaches.

Hierarchical Reinforcement Learning-Based Routing Algorithm With Grouped RSU in Urban VANETs

Q. Yang and S.-J. Yoo

A hierarchical Q-learning-based routing algorithm (HQGR) that integrates grouped RSU for urban VANETs is proposed. The algorithm utilizes multi-agent hierarchical Q-learning to train group and local Q-tables. The group Q-table estimates the reward for reaching the destination group, whereas the local Q-table focuses on reaching the destination RSU inside a group. This hierarchical approach enables a more targeted and efficient routing decision-making process.

Cooperative Traffic Signal Control Using a Distributed Agent-Based Deep Reinforcement Learning With Incentive Communication

B. Zhou, Q. Zhou, S. Hu, D. Ma, S. Jin, and D.-H. Lee

In this study, the authors introduce "multi-agent incentive communication deep reinforcement learning (MICDRL)," a novel approach for optimizing dynamic traffic signal systems. MICDRL employs an innovative incentive communication mechanism, enabling agents to exchange tailored messages for improved decision-making and coordination. This method significantly reduces communication overhead by relying on local information while a specialized teammate module leverages temporal data to predict agents' actions, enhancing collective traffic dynamics understanding. The empirical results demonstrate MICDRL's superior performance over current methods, showing marked improvements in traffic metrics such as reduced queue lengths and increased throughput. In addition, the article presents a bespoke Internet of Things (IoT) architecture to optimize data collection and transmission, integral to MICDRL's efficacy. MICDRL is promising to revolutionize urban traffic management by enhancing efficiency and intelligence in response to growing urbanization and complex traffic networks.

A Scheme for Protecting Source Location Privacy Based on Hierarchical Structure in Smart Ocean

G. Han, Y. Chen, H. Wang, Y. He, and J. Peng

A hierarchical structure-based algorithm for protecting source location privacy is proposed. Based on the Ekman drift model, two location privacy protection schemes for different layers have been proposed separately. In the static layer, the source node location privacy is protected using fake source nodes and phantom nodes, while in the dynamic layer, the inducing nodes are employed to enhance the privacy and security of the source node with minimal energy expenditure. Finally, the AUV supports the data collection combined in the static layer and data uploaded in the dynamic layer.

The algorithm improves the safety time by about 50%, reduces the delay by about 20%, and saves the energy by about 36% as compared to the DIS-PLP algorithm.

Modeling Energy Consumption of Small Drones for Swarm Missions

U. C. Cabuk, M. Tosun, O. Dagdeviren, and Y. Ozturk

This article investigates the energy consumption of small drones (<2 kg) in a swarm setting. Extensive test flights were conducted to collect empirical energy data, leading to the development of four energy models: a theoretical model based on flight forces, a linear regression model, a cubic polynomial regression model, and a machine learning model utilizing the XGBoost Regressor. A unique cost function for swarm topology control was also formulated to optimize energy efficiency in operations like connectivity restoration. Findings identify an optimal energy consumption "valley" within a specific airspeed range, which indicates that drones require less energy when flying at modest speeds compared to hovering or moving at extreme speeds. The machine learning model exhibited outstanding accuracy ($R^2 = 0.9999$) within its training range, while the polynomial model was effective for extrapolations ($R^2 = 0.966$). Simpler models, although less precise, provide rapid energy estimations and insights, altogether aiding in more energy-efficient drone swarm management.

SEGAC: Sample Efficient Generalized Actor Critic for the Stochastic On-Time Arrival Problem

H. Guo, Z. He, W. Sheng, Z. Cao, Y. Zhou, and W. Gao

This article studies the stochastic on-time arrival (SOTA) problem in transportation networks and introduces a novel reinforcement learning-based algorithm, namely, sample efficient generalized actor–critic (SEGAC). Different from almost all canonical SOTA solutions, which are usually computationally expensive and lack generalizability to unforeseen destination nodes, SEGAC offers the following appealing characteristics. SEGAC updates the ego vehicle's navigation policy in a sample efficient manner, reduces the variance of both value network and policy network during training, and is automatically adaptive to new destinations. Furthermore, the pre-trained SEGAC policy network enables its real-time decision-making ability within seconds, outperforming state-of-the-art SOTA algorithms in simulations across various transportation networks.

Amplitude Saturated Nonlinear Output Feedback Controller Design for Underactuated 5-DOF Tower Cranes Without Velocity Measurement

J. Xia and H. Ouyang

Tower cranes are typical underactuated systems commonly used on land as a large transport device. Moreover, workers regularly move loads and adjust the length of the rope simultaneously to improve the efficiency of crane transport. However, most of these methods require accurate velocity feedback and do not take into account the lifetime of the driving motor and variable rope length, leading to frequent safety accidents in practical working conditions. Therefore, in this article, the authors propose an amplitude-saturated nonlinear output feedback controller for five-degree-of-freedom (5-DOF) underactuated tower cranes without velocity measurement. First, all studies are based on a variable rope-length tower crane system. Second, an amplitude-saturated nonlinear output feedback controller without velocity measurement is designed. Furthermore, the Lyapunov theorem and LaSalle's invariance principle are used to prove the asymptotic stability of the closed-loop system at the target position. Finally, they experimentally demonstrate the effectiveness of the proposed controller.

A Battery Prognostics and Health Management Technique Based on Knee Critical Interval and Linear Complexity Self-Attention Transformer in Electric Vehicles

Y. Ma, J. Li, Y. Hu, and H. Chen

An intelligent transformer network with an improved self-attention mechanism based on data from the key interval area is proposed in this article. First, the knee-point and knee-onset in the capacity decay curve of the battery are identified by the Bacon–Watts model. The feature data that does not meet the minimum aging period between the knee-point and knee-onset in the aging curve is eliminated to ensure the accuracy and quickness of the prediction. Second, the denoising autoencoder is used to mine the correlation between the aging characteristics in this interval and the low-dimensional hidden feature of battery aging is reconstructed. Finally, the Transformer network with an improved multi-head self-attention mechanism is taken to capture the dependencies between features at different positions. The simulation results demonstrate that the method can provide a more accurate and faster health prognosis for batteries.

Contrasting Estimation of Pattern Prototypes for Anomaly Detection in Urban Crowd Flow

Y. Wang, X. Luo, and Z. Zhou

A smart system using deep learning to spot unusual patterns in city crowds is created. The proposed method learns distinguishable representations (named as prototypes) of coexisting spatiotemporal factors affecting normal crowd flow. It subsequently identifies anomalous samples by comparing them with their normal counterparts, estimated based on the prototypes. Experimental evaluations on real-world datasets demonstrate the proposed method's superior performance.

Achieving Energy-Efficient and Travel Time-Optimized Trajectory and Signal Control for CAEVs

H. Chen, F. Wu, and T. Z. Qiu

Unlike traditional gasoline-powered vehicles, electric vehicles experience a notable increase in energy consumption at speeds exceeding 25 km/h. Consequently, minimizing energy consumption often results in reduced speed and longer total travel time. Therefore, this article proposes a novel trajectory and signal control method that leverages CAV technology to realize a trade-off between energy consumption and total travel time. Initially, the approach assumes all vehicles are capable of communication and coordination, to which a CACC model was applied. Then, vehicle speed was controlled to avoid stops and achieve smoother trajectories at the intersections. Finally, the signal optimization was integrated to further reduce energy consumption and travel time. Verified by simulation, the developed method successfully reached a compromise between energy consumption and total travel time.

Guard-Net: Lightweight Stereo Matching Network via Global and Uncertainty-Aware Refinement for Autonomous Driving

Y. Liu, X. Zhang, Y. Luo, Q. Hao, J. Su, and G. Cai

Stereo-matching is a prominent research area in autonomous driving and computer vision. Despite significant progress made by learning-based methods, accurately predicting disparities in hazardous regions, which is crucial for ensuring safe vehicle operation, remains challenging. In this article, the authors proposed Guard-Net, a lightweight stereo-matching network designed for real-time, end-to-end disparity estimation. Specifically, they exploited an efficient global enhanced path to provide global representations in ill-posed regions. In addition, they incorporated high-frequency detailed information of the original image along with adaptive uncertainty into the design of a disparity refinement network. This integration facilitates the estimation of high-precision disparity, particularly in hazardous regions. The extensive experimental results reveal that Guard-Net, achieving state-of-the-art performance on the SceneFlow dataset, requires a mere 3.60M parameters. Comprehensive qualitative and quantitative analyses of the KITTI 2012 and KITTI 2015 datasets indicate that Guard-Net achieves superior overall performance in trade-off speed and accuracy.

Unveiling the Impact of Cognitive Distraction on Cyclists Psycho-Behavioral Responses in an Immersive Virtual Environment

X. Guo, A. Tavakoli, T. D. Chen, and A. Heydarian

The National Highway Traffic Safety Administration reported that the number of bicyclist fatalities has increased by more than 35% since 2010. One of the main reasons associated with cyclist' crashes is the adverse effect of drivers' cognitive distractions. However, very limited studies have evaluated the impact of cyclists' cognitive distraction on their behaviors and safety. This study leverages an immersive virtual environment (IVE) simulation environment to explore the effect of secondary tasks on cyclists' cognitive distraction by evaluating their behavioral and physiological responses. Specifically, by recruiting 75 participants, this study explores the effect of listening to music versus talking on the phone as standardized secondary tasks on participants' behavior (i.e., speed, lane position, input power, and head movement) as well as, physiological responses including participants' heart rate variability (HRV) and skin conductance metrics. The results show that listening to high-tempo music can lead to a significantly higher speed, a lower standard deviation of speed, and higher input power. In addition, the trend is more significant for cyclists who have a strong habit of daily music listening (>4 h/day). In the high cognitive workload situation (simulated hands-free phone talking), cyclists had a lower speed with less input power and less head movement variation. The results indicate that participants' HRV features (the power of high frequency, pnni-50) and electrodermal activity (EDA) features like numbers of skin conductance responses (SCRs) peaks are sensitive to cyclists' cognitive load changes in the IVE simulator. Gender differences are identified in cycling performance and physiological response.

A UAV-Assisted Authentication Protocol for Internet of Vehicles

J. Miao, Z. Wang, X. Ning, A. Shankar, C. Maple, and J. J. P. C. Rodrigues

Due to the openness of IoV and the high-speed movement of vehicles, authentication, and privacy issues are one of the most pressing issues in IoV. Therefore, the article proposes a secure and effective authentication protocol for UAV-assisted IoV. The protocol utilizes elliptic curve cryptography to assure the security of the authentication. The protocol undergoes proof of security, Burrows–Abadi–Needham (BAN) logic analysis, and informal security analysis to ensure secure and mutual authentication and have a good resistance to known attacks. Furthermore, performance analysis and comparison are conducted to evaluate the efficiency of the protocol. The results indicate that the protocol has superior advantages in overhead.

A K-Shape Clustering Based Transformer-Decoder Model for Predicting Multi-Step Potentials of Urban Mobility Field

H. Yang, C. Yan, Z. Chen, and P. Wang

This article proposes to use the potentials of the urban mobility field to identify the travel hotspots and develop a K-shape clustering transformer-decoder (KSC-TD) model to predict multi-step potentials. The K-shape clustering method is used to cluster the grids with similar potential time series, and the transformer-decoder model is trained for each cluster of grids. The results show the effectiveness of the proposed model in anticipating urban travel hotspots.

CBAM-Optimized Automatic Segmentation and Reconstruction System for Monocular Images With Asphalt Pavement Potholes

J. Dong, N. Wang, H. Fang, Y. Shen, B. Li, D. Di and K. Zhai

A new convolutional block attention module (CBAM) optimized pothole segmentation and reconstruction system for monocular images is proposed. First, a network called CBAM-Seg-CapsNet is developed to accurately segment pothole areas from two-dimensional monocular images of pavement. The influence of "false potholes" on the reconstruction of real potholes is avoided. Second, an unsupervised monomural depth estimation intelligent network, called "CBAM-Recon-Depth," is developed to realize effective reconstruction of the segmented pothole area. The expensive problem of 3-D reconstruction methods, based on lasers and depth cameras, is solved. Compared with some famous segmentation reconstruction models, this system has better performance. The results show that the CBAM optimization system can accurately extract the pothole area and realize the high-precision reconstruction of pothole damage after extraction.

IR-STP: Enhancing Autonomous Driving With Interaction Reasoning in Spatio-Temporal Planning

Y. Chen, J. Cheng, L. Gan, S. Wang, H. Liu, X. Mei, and M. Liu

This article introduces an interactive motion planning framework for autonomous driving, based on prediction results. The interaction relationships are recorded and updated for every planned state through a forward spatio-temporal search process, guided by the interaction formulations put forth. These formulations clarify appropriate interaction dynamics, encompassing reactions (e.g., overtaking and yielding), and delineate strategies to influence the trajectories of other agents, providing guidance on the timing and execution of these actions. The experimental results demonstrate the effectiveness and robustness of the method across diverse simulation conditions, accounting for variations in prediction accuracy, modality, and planner aggressiveness levels.

A Hierarchical Hybrid Learning Framework for Multi-Agent Trajectory Prediction

Y. Jiao, M. Miao, Z. Yin, C. Lei, X. Zhu, X. Zhao, L. Nie, and B. Tao

A hierarchical hybrid framework that combines deep learning (DL) and reinforcement learning (RL) for multi-agent trajectory prediction is proposed to address the issue that DL methods often generate invalid predictions by capturing multi-scale interactions that shape future motion. In the DL stage, a Transformer-style graph neural network (GNN) is employed to encode heterogeneous interactions at intermediate and global scales, predicting multi-modal intentions as key future positions for agents. In the RL stage, the scene is divided into local scenes based on DL predictions. A transformer-based proximal policy optimization (PPO) model, incorporated with vehicle kinematics, generates future trajectories in the form of motion planning shaped by microscopic interactions and guided by multi-objective rewards for balanced agent-centric accuracy and scene-wise compatibility. The experimental results demonstrate that the proposed framework enhances trajectory prediction feasibility and plausibility in interactive scenes.

Joint Task Offloading and Resources Allocation for Hybrid Vehicle Edge Computing Systems

L. Yin, J. Luo, C. Qiu, C. Wang, and Y. Qiao

Vehicle edge computing (VEC) leverages the computational resources available at edge nodes to alleviate the strain on public network transmission and reduce task processing latency. However, the dynamic nature of the vehicle environment, the challenge of incentivizing vehicles to share idle resources, and the uncertainty surrounding the number of resources shared by vehicles present significant obstacles in designing task offloading and resource allocation methods for VEC systems. To maximize the benefits derived from task vehicles, RSUs, and shared resource vehicles, the authors first introduce an adaptive type selection algorithm (ALTS) for shared resource vehicles based on the multi-armed bandit (MAB) theory. The experimental results demonstrate the superiority of the proposed ALTS algorithm over existing learning algorithms, thereby showcasing the effectiveness of the lease contract and the three-party transaction mechanism.

Self-Powered Wireless Devices and Machine Learning Enable Local Humidity Monitoring

Y. Zhou, X. Cui, and Y. Zhang

Self-powered wireless sensors are a promising design paradigm for Internet of Things (IoT) devices that need to enable continuous, real-time environmental monitoring using energy harvesting devices. The typical low energy density of environmental energy has limited self-powered wireless sensors' long-term operation in laboratory settings and prevented their widespread and large-scale deployment. Currently available energy harvesting devices such as the triboelectric nanogenerator (TENG), generally have either millimetre-scale environmental monitoring devices or self-powered wireless transmitters, but not both. A battery-free wireless moisture meter with a simple structure and high accuracy has been developed using off-the-shelf parts, which can be suitable for various sensor and artificial intelligence applications.

Inventory Routing Problem With Split Delivery and Variable Time Windows for Customers With Small Capacity and Large Sales

Z. Liu and X. Zuo

A supplier determines both delivery orders of customers and vehicle routes in push delivery mode. Some customers have small inventory capacity and rapid sale speed (called small-C/S customers). Thus, each of them needs to receive multiple deliveries in a work shift. The number of deliveries and quantity of each delivery for a customer is unknown. Each delivery has a pair of variable accommodation times and stockout times. This work proposes a single-period inventory routing problem with split delivery and variable time windows for small-C/S customers (SIRSC). A mathematical programming model is developed for SIRSC, to minimize the sum of transportation and stockout costs. A hybrid ant colony optimization with variable neighborhood search (ACO-VNS) is proposed to solve SIRSC. A distribution network model of ACO is developed and several problem-specific neighborhood structures are designed. The experimental results show that the approach can effectively solve SIRSC.

Computation Offloading for Integrated Satellite-Terrestrial Internet of Vehicles in 6G Edge Network: A Cooperative Stackelberg Game

Z.-Y. Chai, H.-S. Kang, Y.-L. Li, Y.-J. Zhao, and H. Huang

A new integrated satellite-terrestrial Internet of Vehicles (IST-IOV) environment is proposed, implementing high-performance vehicle communication under the management of edge service providers. To handle complex tasks and data flows, a computational offloading algorithm based on a dynamic cooperative Stackelberg game was also proposed. The experimental results show that the framework and algorithm have excellent robustness and practicality.

TPV-IGKD: Image-Guided Knowledge Distillation for 3D Semantic Segmentation With Tri-Plane-View

J.-C. Li, J.-G. Lu, M. Wei, H.-Y. Kang, and Q.-H. Zhang

This article proposes an image-guided knowledge distillation framework based on a tri-plane view to resolve the conflicts between accuracy and running speed in 3-D segmentation. The image and point cloud features are first represented in an efficient 3-D tri-plane-view space, which facilitates feature alignment and fusion. The object movements can be predicted in such a unified 3-D space to fully utilize the time information to address the issue of the differences in the fields of view between the camera and LiDAR. The fusion knowledge is transferred to the pure 3-D network using knowledge distillation, so only the point cloud branch is needed during inference, thus achieving real-time deployment. The results on two large benchmarks and outdoor driving scenarios show that the proposed method improves the baselines' performance and the work can serve as a general framework for multi-modality semantic segmentation.

High-Speed Train Positioning Using Improved Extended Kalman Filter With 5G NR Signals

T. Wen, H. Jiang, B. Cai, and C. Roberts

With the integration of 5G NR into railway systems, the demand for enhanced positioning and trajectory-tracking performance in high-speed train networks has grown. However, many existing train positioning schemes rely on traditional algorithms, which may fall short of meeting the precision requirements. Addressing this limitation, this article introduces an improved extended Kalman filter using the least squares of the under-measurement technique, specifically tailored for nonlinear systems. The IEKF, expanding step by step, theoretically captures the statistical properties of the Knorr set for any order prediction error, providing richer information on higher-order terms. In addition, for a more intuitive comparison of the IEKF unfolded to different orders, a novel performance indicator is introduced. In conclusion, based on simulation examples involving train localization tracking and an industrial device ablation system, the authors demonstrate its superior localization performance by comparing mean squared error and mean absolute error with traditional nonlinear localization algorithms.

A Two-Layer Dynamic ECU Group Management Scheme for In-Vehicle CAN Bus

Y. Shen, J. Cui, H. Zhong, J. Zhang, I. Bolodurina, and D. He

To enable the vehicle control system to provide better service, an increasing number of network nodes are being introduced into the vehicle; this also dramatically expands the attack surface of modern vehicles. In recent years, the security of vehicle communication buses and electronic control units (ECUs) has been extensively studied. However, in actual deployment, there is little concern for the fine management of secure communication schemes with respect to the security level of the ECU on the controller area network (CAN). On this basis, this article proposes a two-layer ECU group dynamic management scheme based on the Chinese remainder theorem. Dynamic grouping management based on the credibility of ECUs while the vehicle is running can effectively balance efficiency and security. During communication, different groups use different modes to achieve higher efficiency. Security analysis shows that the proposed scheme can satisfy the requirements of security and privacy. The simulation results further demonstrate that the proposed scheme performs well in terms of computing and communication costs.

URLLC-Aware Proactive UAV Placement in Internet of Vehicles

C.-F. Liu, N. D. Wickramasinghe, H. A. Suraweera, M. Bennis, and M. Debbah

The authors study the UAV placement problem in the Internet of Vehicles, where the UAV is deployed to monitor road traffic and send the monitored videos to vehicles. The studied problem is formulated as video resolution maximization by optimizing over the UAV's position. Moreover, they take into account the maximal transmission delay and impose a probabilistic constraint. To solve the formulated problem, they first leverage the techniques in extreme value theory and Gaussian process regression to characterize the influence of the UAV's position on the delay performance. Based on this characterization, they subsequently propose a proactive resolution selection and UAV placement approach, which adaptively places the UAV according to the geographic distribution of vehicles.

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