A New Era of Intelligent Vehicles and Intelligent Transportation Systems: Digital Twins and Parallel Intelligence

Dear All,

First, I would like to share with you the following items:

- By March 25, our transaction has received a total of 619 original submissions. Our current average number of submissions per day (SPD) rate is 7.37. Given this SPD, I would like to expand our editorial board to include at least 120 members to ensure the review quality of services.
- I would like to share my philosophy on reviewing assignments for submissions. First, I would assign papers to AEs without assignments and with less than six assignments for the year. Second, I will consider their fields of expertise. In this way, I would like to push our AEs, especially the senior ones, to go out of their own comfort zones for paper reviewing. Why? Technology, especially intelligent technology, changes so fast, we must be prepared to process papers that are outside our specialties at TIV or any other academic publications.
- On January 14, 2023, I reported the state of IEEE TIV as well as its future directions to IEEE ITSS Publication Board, received very positive feedback, and then sent the annual report to the TIV Steering Committee (SC). On March 4th, I received a notice from the SC for a meeting on March 13th. The only action item from the SC meeting was to have two meetings annually in the future, as suggested by our former EiC and current Chair, Prof. Umit Ozguner. However, no discussion on our proposed list of Associate Editors at the meeting, so all 28 new AEs become official after March 15, 2023. Welcome on the IEEE TIV board, our future is in your hand now.
- Our first Special Issue (SI) on "*Digital Twins and Parallel Intelligence for Intelligent Vehicles and Intelligent Transportation Systems*" has received a total of 81 submissions, out of which 18 top-quality papers were selected for the final publication [1]. I would like to take this opportunity to thank our SI Guest Editors, especially Drs. Ziran Wang and Chen Lv, for their tremendous effort and professional dedication. You will see the SI papers in this issue, and hope they will promote research and development in digital twins and parallel intelligence.

In additional to SI papers, the current issue includes 2 letters and 33 regular papers. The two letters are resulted from our decentralized and hybrid workshops (DHW) on Sustainability for Transportation and Logistics (STL) and Data Science for Intelligent Vehicles (DSiV).

After **Scanning the Issue**, I will join our leading SI guest editors to address issues related to Digital Twins and Parallel Intelligence (DTPI). So far, we have already conducted 1 Conference, 2 decentralized and hybrid symposia (DHS), and 3 DHWs on DTPI. We will summarize the key points presented at those meetings, especially the latest developments in DTPI and their applications in IV and ITS.

I. Scanning the Issue

Special Issue Papers

Predictive Cruise Control Under Cloud Control System for Urban Bus Considering Queue Dissipation Time

B. Gao, Q. Chen, Y. Liu, K. Wan and K. Li

Prior research has predictive cruise controlled under Intelligent Transportation System, which is not feasible to directly communicate with controllers' units of Intelligent Connected Vehicles. Besides, the effect of queue dissipation is a topic that has received less attention in recent related work. Therefore, this paper proposes a vehicle-cloud hierarchical architecture based on Cloud Control System at first, under which a predictive cruise control for urban buses is deployed. Given the impact of intersection queue length and dissipation time on vehicle driving, a queue dissipation time estimation model based on shockwave theory is proposed to predict changes in intersection traffic state. The queue dissipation time equivalent to the extension of the red-light window is reflected in the constraints of the Receding Distance Horizon Dynamic Programming (RDHDP) algorithm for solving the optimal control problem. Eventually, comparison simulations, a segment of realistic trip between adjacent stops, are presented.

Learning for Vehicle-to-Vehicle Cooperative Perception Under Lossy Communication

J. Li et al.

Deep learning has been widely used in the perception (e.g., 3D object detection) of intelligent vehicle driving. Due to the

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beneficial Vehicle-to-Vehicle (V2V) communication, the deep learning based features from other agents can be shared to the ego vehicle so as to improve the perception of the ego vehicle. It is named as Cooperative Perception in the V2V research, whose algorithms have been dramatically advanced recently. However, all the existing cooperative perception algorithms assume the ideal V2V communication without considering the possible lossy shared features because of the Lossy Communication (LC) which is common in the complex real-world driving scenarios. In this paper, we first study the side effect (e.g., detection performance drop) by the lossy communication in the V2V Cooperative Perception, and then we propose a novel intermediate LC-aware feature fusion method to relieve the side effect of lossy communication by a LC-aware Repair Network (LCRN) and enhance the interaction between the ego vehicle and other vehicles by a specially designed V2V Attention Module (V2VAM) including intra-vehicle attention of ego vehicle and uncertainty-aware inter-vehicle attention.

Car-Following Behavior of Human-Driven Vehicles in Mixed-Flow Traffic: A Driving Simulator Study

S. Peeta, A. Zhou, Y. Liu, E. Tenenboim and S. Agrawal

Connected and autonomous vehicles (CAVs) and human-driven vehicles (HDVs) will inevitably coexist on roads in the future, creating mixed-flow traffic. The heterogeneous carfollowing (CF) behavior of HDVs can degrade the control performance of CAVs and introduce inefficiencies in CAV operations. To address these challenges, it is necessary to comprehend HDV CF behavior in mixed-flow traffic. This driving simulator-based study investigates HDV CF behavior in mixedflow traffic under three different CAV control settings (stringstable, string-unstable, and HDV-like). The effects of traffic congestion level and demographic characteristics on CF behavior are also considered. Statistical analysis and CF model calibration, based on trajectory data collected from 72 participants in driving simulator experiments, are performed to examine the impacts of these factors on string stability, traffic efficiency, and safety. Then, online parameter estimation is conducted to illustrate the timevarying desired time headway, and sensitivity to spacing and speed variations.

Towards Next Generation of Pedestrian and Connected Vehicle In-the-loop Research: A Digital Twin Co-Simulation Framework

Z. Wang, O. Zheng, L. Li, M. Abdel-Aty and C. Cruz-Neira

In this study, a Digital Twin framework for CV and pedestrian in-the-loop simulation is proposed. The framework consists of the physical world, the digital world, and data transmission in between. A sample architecture under the proposed Digital Twin framework is demonstrated, which is based on Carla-Sumo Co-simulation and Cave automatic virtual environment (CAVE). A case study that investigates Vehicle-Pedestrian (V2P) warning system is conducted to validate the effectiveness of the presented architecture.

Global-Local-Feature-Fused Driver Speech Emotion Detection for Intelligent Cockpit in Automated Driving

W. Li et al.

Affective interaction between the intelligent cockpit and humans is becoming an emerging topic full of opportunities. Robust recognition of the driver's emotions is the first step for affective interaction, and the intelligent cockpit recognizes emotions through the driver's speech, which has a wide range of technical application potential. In this paper, we first proposed a multi-feature fusion parallel structure speech emotion recognition network, which complementarily fuses the global acoustic features and local spectral features of the entire speech. Second, we designed and conducted the speech data collection under the driver's emotion and established the driver's speech emotion (SpeechEmo) dataset in the dynamic driving environment including 40 participants. Finally, the proposed model was validated on the SpeechEmo and public datasets, and quantitative analysis was carried out. It was found that the proposed model achieved advanced recognition performance, and the ablation experiments verified the importance of different components of the model. The proposed model and dataset are beneficial to the realization of human-vehicle affective interaction.

The OpenCDA Open-Source Ecosystem for Cooperative Driving Automation Research

R. Xu et al.

there is an urgent need to establish an open-source ecosystem (OSE) to address the demands of different communities for CDA research, particularly in the early exploratory research stages, and provide the bridge to ensure an integrated development and testing pipeline that diverse communities can share. In this paper, we introduce the OpenCDA research ecosystem, a unified OSE integrated with a model zoo, a suite of driving simulators at various resolutions, large-scale real-world and simulated datasets, complete devel-opment toolkits for benchmark training/testing, and a scenario database/generator. We also demonstrate the effectiveness of OpenCDA OSE through example use cases, including cooperative 3D LiDAR detection, cooperative merge, cooperative camera-based map prediction, and adversarial scenario generation.

Control Sequences Generation for Testing Vehicle Extreme Operating Conditions Based on Latent Feature Space Sampling

Y. Zhu, Z. Li, F. Wang and L. Li

This paper proposes a method for generating control sequences that are capable of pushing vehicles towards extreme operating conditions. A LSTM-VAE hybrid model is implemented to construct a latent feature space of the collected control sequences. By selecting proper sampling regions in the latent feature space, we can sample hidden feature value and generate target control sequences. These sequences can be used for vehicle simulation tests.

Mixed Cloud Control Testbed: Validating Vehicle-Road-Cloud Integration via Mixed Digital Twin

J. Dong et al.

In this paper, we introduce our miniature experimental platform, Mixed Cloud Control Testbed (MCCT), developed based on a new notion of Mixed Digital Twin (mixedDT). Combining Mixed Reality with Digital Twin, mixedDT integrates the virtual and physical spaces into a mixed one, where physical entities coexist and interact with virtual entities via their digital counterparts. Under the framework of mixedDT, MCCT contains three major experimental platforms in the physical, virtual and mixed spaces respectively, and provides a unified access for various human-machine interfaces and external devices such as driving simulators. A cloud unit, where the mixed experimental platform is deployed, is responsible for fusing multi-platform information and assigning control instructions, contributing to synchronous operation and real-time cross-platform interaction.

Lightweight Edge Intelligence Empowered Near-Crash Detection Towards Real-Time Vehicle Event Logging

R. Ke et al.

A real-time onboard near-crash event detection and logging system with edge artificial intelligence. A parallel edge computing system architecture with low latency in video streaming, dumping data of no interest, triggering event data integration. An efficient near-crash detection algorithm enabled by modeling the object bounding boxes and is insensitive to camera intrinsic parameters. In addition, Extensive real-world testing and demonstration of the system were conducted on four transit buses for over a year.

Disturbance Observer-based Cooperative Control of Vehicle Platoons Subject to Mismatched Disturbance

M. Hu, X. Wang, Y. Bian, D. Cao and H. Wang

This paper investigates longitudinal control of vehicle platoons subject to both mismatched velocity disturbance and matched acceleration disturbance. The mismatched and matched disturbances are estimated by a finite-time disturbance observer. Furthermore, two coupled sliding mode platoon controllers are proposed incorporating observed disturbances. By using and extending the coupled sliding mode technique, closed-loop stability and string stability are proved under bidirectional and predecessor-following topologies, respectively. Simulations and an experiment are conducted to validate the performance of the proposed controllers.

Online Learning-Informed Feedforward-Feedback Controller Synthesis for Path Tracking of Autonomous Vehicles

H. Chen and C. Lv

This study introduces the recurrent high-order neural network (RHONN) – to characterize vehicle behaviors with a high fidelity and flexible form. The online-identified RHONN model finds the equilibrium at the preview point on the desired path to generate the feedforward command. The preview point position-based algorithm incorporating the steady vehicle sideslip angle is taken as the feedback steering controller. The validation results reveal that the proposed approach offers better tracking accuracy in linear and nonlinear regions than other techniques.

A Parallel Intelligence-Driven Resource Scheduling Scheme for Digital Twins-Based Intelligent Vehicular Systems

J. Yang, F. Lin, C. Chakraborty, K. Yu and Z. Guo

Real-time digital twin technology can enhance traffic safety of intelligent vehicular system and provide scientific strategies for intelligent traffic management. At the same time, real-time digital twin depends on strong computation from vehicle side to cloud side. Aiming at the problem of delay caused by the dual dependency of timing and data between computation tasks, and the problem of unbalanced load of mobile edge computing servers, a parallel intelligence-driven resource scheduling scheme for computation tasks with dual dependencies of timing and data in the intelligent vehicular systems (IVS) is proposed. First, the delay and energy consumption models of each computing platform are formulated by considering the dual dependence of sub-tasks. Then, based on the bidding idea of the auction algorithm, the allocation model of computing resources and communication resources is defined, and the load balance model of the mobile edge computing (MEC) server cluster is formulated according to the load status of each MEC server. Secondly, joint optimization problem for offloading, resource allocation, and load balance is formulated. Finally, an adaptive particle swarm with genetic algorithm is proposed to solve the optimization problem.

Lane-Level Navigation Based Eco-Approach

J. Hu et al.

An eco-approach planner system is established to realize lane-level navigation based eco-approach. It has the following features: i) with deeper consideration on mobility; ii) with enhanced practicality; iii) with an expanded target market for human driven vehicles on top of automated vehicles; iv) with a new structure laying the foundation for infrastructure enabled cooperative driving; v) with upgraded formulation to guarantee convergence. The performance of the proposed eco-approach planner system was evaluated in a software-in-the-loop simulation platform. The platform was previously developed by this research team and published in Transportation Research Part C. The influences of different arrival types and traffic congestion levels on the performance were analyzed. Experiment results showed that applying the planner system can reduce fuel consumption while maintaining the best feasible mobility level.

DRL-Based Computation Offloading With Queue Stability for Vehicular-Cloud-Assisted Mobile Edge Computing Systems

G. Ma et al.

This paper proposes a vehicular-cloud-assisted MEC network for computation offloading. The proposed offloading scheme aims to maximize the average task throughput in continuous time slots subject to multi-constraint. The Lyapunov optimization and deep reinforcement learning are applied to solve the proposed problem. The simulation results show that the proposed scheme can achieve the task queue stability within 10 time slots with a low transmission power.

Real-Time Dynamic Map With Crowdsourcing Vehicles in Edge Computing

Q. Liu, T. Han, J. Xie and B. Kim

The perception of autonomous driving systems can be compromised under diversified environmental uncertainties. We propose a novel real time dynamic map (LiveMap) to crowdsource sensing data and share perception information among connected and automated vehicles. We achieve subsecond-level object detection, matching, and tracking on the road with unique data plane development and intelligent control plane design.

Event-Triggered Deep Reinforcement Learning Using Parallel Control: A Case Study on Autonomous Driving

J. Lu, L. Han, X. Dai and F.-Y. Wang

This paper investigates the problem of event-triggered deep reinforcement learning and develops an event-triggered deep Q-network (ETDQN) for autonomous driving, without training an explicit triggering condition. The ETDQN incorporates information of actions into the feedback and constructs a dynamic control policy using parallel control. The ETDQN determines whether the previous action applies to the current state through the augmented action-value function and realizes ETC. Meanwhile, the implicit triggering condition and the control policy share deep neural network parameters.

Parallel Training: An ACP-Based Training Framework for Iterative Learning in Uncertain Driving Spaces

J. Wang, X. Wang, Y. Tian, Y. Wang and J. Niu

In this paper, we develop a parallel training method based on artificial systems, computational experiments, and parallel execution (ACP) for the intelligent optimization and learning of the aforementioned agents in uncertain driving spaces. With the guidance of parallel training, virtual and real-world driving spaces are set up in parallel and interact frequently. They are closely linked and unified in opposition to each other, ultimately building a parallel driving system that fulfills safety, security, sustainability, sensitivity, service, and smartness (6S).

Parallel and Collaborative Passenger Flow Control of Urban Rail Transit Under Comprehensive Emergency Situation

G. Zhu, R. Sun, X. Sun, Y. Wei and B. Wu

Collaborative passenger control is hard but important for congestion relieving of urban rail transit under comprehensive emergency situation. Considering the demand of operation and passenger integration, a parallel model is established. An improved MIS-NSGA-II is designed to solve the complex multi-objective nonlinear integer programming model. The simulation results show that the model is efficient at congestion alleviating at stations and operation sections under emergency. The comprehensive performance is improved, from multi-aspects such as safety, fairness of passenger travel, etc.

Regular Papers

CACC Simulation Platform Designed for Urban Scenes

J. Hu et al.

A simulation platform is designed to evaluate and validate Cooperative Adaptive Cruise Control (CACC) technology in urban scenes. It is able to: i) plug in production Connected and Automated Vehicle (CAV) control systems; ii) capture the interaction between human-driven vehicles and CAVs; iii) evaluate CACC with regard to various traffic control; iv) quantify CACC safety in urban scenes; v) assess the impact of CACC on mobility in urban scenes. The platform is credible compared against field tests and theoretical studies.

Density-Imbalance-Eased LiDAR Point Cloud Upsampling via Feature Consistency Learning

T. Chen, C. Hsiao and C. Huang

A novel LiDAR-based point cloud upsampling network (LiUpNet) is proposed. By introducing a transformer-based local structure attentive feature extractor, a novel density-invariant feature consistency learning strategy, and a manifold-based upsampler, LiUpNet upsampling scheme can tackle the density-imbalance problem of a LiDAR-based point cloud. The experimental results demonstrate the superior performance of LiUpNet both in upsampling complex real-world scenes and single-object point cloud; the ability to assist the downstream tasks with significant improvement also supports the practical values of LiUpNet.

Safety-Balanced Driving-Style Aware Trajectory Planning in Intersection Scenarios With Uncertain Environment

X. Wang et al.

This paper presents a two-stage trajectory planning strategy for self-driving vehicles (SDVs) navigating intersections. It aims to tackle the challenge of SDV trajectory planning posed by the unpredictable behavior of other drivers. The method consists of a driving-style-sensitive motion planning stage and a safety

verification stage. In the first stage, the method predicts multiple potential trajectories of human drivers and generates candidate SDV trajectories. The second stage evaluates the safety of these candidate trajectories and selects the one with the optimal safety-performance balance. The experimental results verify the efficacy, robustness, and practicality of the proposed approach in accounting for the dynamic driving styles of human drivers in intersection scenarios.

Byzantine Resilient Joint Localization and Target Tracking of Multi-Vehicle Systems

Y. Cui et al.

This work investigates the problem of joint localization and target tracking (JLATT) of multi-vehicle systems (MVSs) in the presence of Byzantine attacks (BAs). For MVSs, there may exist malicious and misbehaving vehicles, called Byzantine vehicles, which act as deceivers and pass false information to their neighbors. For the first time, we formulate a resilient JLATT framework to synthesize the hybrid problems of distributed cooperative localization and flock tracking in the presence of BAs. More specifically, we propose a covariance weighted mean-subsequence-filter (CW-MSF) algorithm to guarantee that the MVS achieves flock tracking w.r.t a target even in the presence of a certain fraction of Byzantine vehicles. Note that this resilient JLATT scheme does not require global information and thus it is fully distributed.

Prediction-Uncertainty-Aware Threat Detection for ADAS: A Case Study on Lane-Keeping Assistance

J. Dahl, G. Campos and J. Fredriksson

This article evaluates how machine learning-based prediction models can estimate prediction uncertainty in real-time to improve ADAS. It proposes four threat-detection methods that leverage uncertainty information to improve the system's robustness and ensure trustworthy predictions. The methods are evaluated using a real-world dataset in the context of a lane-keeping assistance application. The results show that these methods have the potential to improve ADAS's performance, particularly in situations where input data is affected by noise or anomalies not present in the training data.

Discrete Multi-Objective Switching Topology Sliding Mode Control of Connected Autonomous Vehicles With Packet Loss

Y. Yan, H. Du, Q. Han and W. Li

This paper provides a real-time switching topology technique for improving the platoon's performance under various types of imperfect communication situations and constant packet dropout rates. First, a discrete sliding mode controller with a double power reaching law is designed for a nonlinear heterogeneous vehicle dynamic model with packet loss. Then, Lyapunov analysis is applied to ensure the platoon's stability and string stability. Finally, a two-step switching topology framework is introduced. As a result, the platoon's overall performance is improved.

Moment-Based Model Predictive Control of Autonomous Systems

H. Bao et al.

Great efforts have been devoted to the intelligent control of autonomous systems. Yet, most of existing methods fail to effectively handle the uncertainty of their environment and models. Uncertain locations of dynamic obstacles pose a major challenge for their optimal control and safety, while their linearization or simplified system models reduce their actual performance. To address them, this paper presents a new model predictive control framework with finite samples and a Gaussian model, resulting in a chance-constrained program. Its nominal model is combined with a Gaussian process. Its residual model uncertainty is learned. The resulting method addresses an efficiently solvable approximate formulation of a stochastic optimal control problem by using approximations for efficient computation. There is no perfect distribution knowledge of a dynamic obstacle's location uncertainty. Only finite samples from sensors or past data are available for moment estimation. We use the uncertainty propagation of a system's state and obstacles' locations to derive a general collision avoidance condition under tight concentration bounds on the error of the estimated moments. Thus, this condition is suitable for different obstacles, e.g., bounding box and ellipsoid obstacles.

MUGAN: Thermal Infrared Image Colorization Using Mixed-Skipping UNet and Generative Adversarial Network

H. Liao et al.

Thermal infrared (TIR) cameras can effectively capture the targets during daytime and nighttime. Since TIR images are usually grayscale and lack detail features, they are not conducive to subsequent observation and processing. This paper proposes an automatic TIR image colorization method that can translate TIR images into colorful visible image and restore majority of the texture information. Extensive experiments reveal the superiority of our method in the task of TIR image colorization.

Quantifying the LiDAR Sim-to-Real Domain Shift: A Detailed Investigation Using Object Detectors and Analyzing Point Clouds at Target-Level

S. Huch, L. Scalerandi, E. Rivera and M. Lienkamp

The use of simulated data to train LiDAR object detection neural networks can result in a domain shift between simulated and real-world data, owing to differences in scenes, scenarios, and distributions. In this study, the sim-to-real domain shift of LiDAR object detectors trained with a new scenario-identical real-world and simulated dataset was quantified. The extensive

analyses carried out in this study revealed a significant sim-to-real domain shift even for scenario-identical datasets.

An Air-to-Ground Relay Communication Planning Method for UAVs Swarm Applications

D. Yin, X. Yang, H. Yu, S. Chen and C. Wang

A planning method of relay Unmanned Aerial Vehicles(UAVs) is presented to assist in data transmission between UAV swarm and ground control station(GCS). Based on the UAV-to-GCS and UAV-to-UAV communication models, a mixed integer nonlinear programming problem(MINLP) is constructed to solve the approximate number of relay nodes and access locations. Then a continuous time-sharing relay UAVs reward model is constructed, and the consensus-based bundle algorithm(CBBA) is adopted to obtain the optimal task sequences and routes of relay UAVs.

An Efficient Multilayered Linkable Ring Signature Scheme With Logarithmic Size for Anonymous Payment in Vehicle-to-Grid Networks

Y. Liu, D. He, Z. Bao, H. Wang and M. Khan

Vehicle-to-Grid (V2G) networks are emerging as an outstanding technique for alleviating energy and environmental concerns. Whereas, malicious attackers thirst for private information from frequent electricity/service exchanges between electric vehicles (EVs) and smart grids (SG) in V2G networks. Several attempts have been made to use ring signatures to achieve privacy-preserving payment and ensure reliable services in V2G. Nevertheless, most of the existing ring signature-based payment proposals may still have numerous limitations in the V2G paradigm due to their heavy signature size. To address the aforementioned problem, we propose Emularis, an efficient multilayered linkable ring signature scheme with a logarithmic size. Specifically, we implement an anonymous payment scheme for V2G using Emularis. We then prove that Emularis guarantees security and privacy requirements through rigorous security analysis. Furthermore, our scheme significantly outperforms existing schemes in terms of communication and computation costs. Extensive experimental results indicate that our scheme is suitable for deployment in V2G security-related applications.

Cross-Modal Supervision-Based Multitask Learning With Automotive Radar Raw Data

Y. Jin, A. Deligiannis, J. Fuentes-Michel and M. Vossiek

This paper proposes a novel camera-radar system concept that can automatically train deep neural networks with radar raw data utilizing the pseudolabel provided by the camera to achieve the free space segmentation and object detection tasks simultaneously. This method largely alleviates the labeling expense and accomplishes better performances than previous works in these two tasks.

Deep Reinforcement Learning Based PHEV Energy Management with Co-Recognition for Traffic Condition and Driving Style

N. Cui, W. Cui and Y. Shi

In this paper, a novel twin delayed deep deterministic police gradient (TD3) algorithm based EMS integrating co-recognition for driving style and traffic condition is proposed, aiming to improve the generalization ability of EMS in various application scenarios with superior energy saving performance and higher self-learning efficiency. In particular, the TD3 based energy management architecture combining delayed policy update and smooth regularization technologies is studied to achieve simultaneous improvement for PHEV energy efficiency and strategy convergence speed. Furthermore, the traffic conditions are recognized by fuzzy C-means method, while the local minimum problem is effectively avoided by incorporating simulated annealing (SA) and genetic algorithm (GA). Sequentially, the driving styles are decoupled from recognized traffic condition, which are further recognized as three typical styles. The comparison results of the proposed strategy with several representative deep reinforcement learning based EMSs indicate that the TD3 based EMS outperforms DDQN and DDPG based EMSs in terms of convergence speed and energy saving performance.

Goal-Aware RSS for Complex Scenarios via Program Logic

I. Hasuo et al.

Responsibility-sensitive safety (RSS) is an approach to automated driving safety that offers absolute and explainable safety guarantees in the form of mathematical proofs. We present a "goal-aware" extension of RSS, an essential extension when RSS is applied to complex scenarios that also concern goal achievements (e.g., safe pull over). Its technical key enabler, namely our compositional reasoning framework based on program logic, builds upon logical techniques in software science.

Lateral Shared Sliding Mode Control for Lane-Keeping Assist System in Steer-by-Wire Vehicles: Theory and Experiments

G. Perozzi, J. Rath, C. Sentouh, J. Floris and J. Popieul

The lane-keeping assistance design for steer-by-wire road vehicles is a multi-objective control problem that addresses lane tracking, improvement of driver comfort and ensuring vehicle stability. The designed architecture must be sensitive to various driver behaviors, provide assistance to drivers whenever required and ensure a smooth transition of authority between manual and automated driving modes. In this work, we propose a novel shared lane-keeping controller-based on quasi-continuous high-order sliding mode control dealing with the above challenges. The parameters of the controller are characterized by an upper bound estimate of the lateral winds force and the road curvature which acts as disturbances. Using the sharing parameter dependent on the monitored driver attribute, the authority is smoothly

transitioned between various modes while accounting for driver behaviors.

Narrowband Jamming Mitigation Based on Multi-Resolution Analysis for Land Vehicles

H. Elghamrawy and A. Noureldin

Autonomous and connected vehicles mainly rely on global navigation satellite systems (GNSS) for positioning and navigation, which is a key component for path planning and guidance. It is therefore crucial to ensure the reliability and robustness of the GNSS signals. Jamming has recently become one of the major concerns for GNSS receivers, especially with the widespread of in-car jammers that broadcast jamming signals. Therefore, future vehicle manufacturers must deploy advanced anti-jamming techniques that have to be extensively tested before being deployed in future self-driving vehicles. This motivates us to develop a robust anti-jamming technique based on wavelet packet transform to efficiently suppress jamming signals and enhance the performance of the acquisition, tracking, and navigation stages within a software-defined receiver. The developed technique is computationally efficient, thus, more suitable for real-time processing. Several experiments for different driving scenarios are performed to verify the effectiveness of the proposed method for mitigating various types of jamming signals.

Performance Limit Evaluation by Evolution Test With Application to Automatic Parking System

G. Feng, Z. Han, J. Zhou and Y. Yang

The efficient detection of the performance limit is critical to automatic driving systems. With the motivation that automatic driving is more difficult to be realized under more complicated scenarios, an improved genetic algorithm (IGA) based evolution test is proposed to accelerate the test process for the performance limit evaluation of automatic driving systems. IGA conducts the crossover operation at all positions and the mutation operation for several times to make the high quality chromosome exist in the candidate offspring easily. Then the normal offspring is selected statistically based on the index of scenario complexity, which is designed to measure the difficulty of automatic driving indirectly by using the Analytic Hierarchy Process. The benefits of the modified cross/mutation operators on the improvement of the scenario complexity are analyzed theoretically. The effectiveness of IGA based evolution test is validated by application to the evaluation of the collision avoidance performance of an automatic parallel parking system.

Two-Step Asynchronous Iterative Formation Control for Heterogeneous Vehicles in Highway Scenarios

M. Zambelli, M. Steinberger, M. Horn and A. Ferrara

In this article a novel algorithm for the on-line control of formations of heterogeneous vehicles is proposed for highway traffic scenarios. A two-step iterative strategy relying on both a discrete and a continuous space representation, using Dynamic Programming and reference tracking via Model Predictive Control, is formulated. It allows the creation and arbitrary reshaping of vehicle formations in a unified context, providing an applicability in a wide range of practical situations. Only position measurements and basic communication capabilities for global coordination are required for the automated vehicles. Scalability and flexibility are achieved by the underlying decoupled structure of the algorithm, while an asynchronous functioning is enforced due to trigger signals that are exchanged between the vehicles and the coordinator. Different scenarios are simulated and discussed to evidence the effectiveness of the proposed strategy.

Identifying Admissible Uncertainty Bounds for the Input of Planning Algorithms

F. Henze, D. Fabender and C. Stiller

To ensure good data processing over the sense-plan-act chain, the quality of the planners input needs to be analyzed: How much uncertainty can the planning module handle while still providing reliable decisions, and are the sensing modules capable of ensuring this quality for the information they provide We present a method that identifies uncertainty bounds for every input such that with a given probability changes in the input, e.g., due to measurement errors, do not lead to unacceptably large deviations in the planning result.For this, we define a stochastic optimization program, which characterizes non-influential inputs with a stochastic constraint, and give a discrete approximation to the problem. To solve it, we extend a multilevel coordinate search by a sensitivity analysis.Finally, we determine accuracy requirements for a longitudinal-lateral driver model in a roundabout scenario.

Online Maneuver Learning and Its Real-Time Application to Automated Driving System for Obstacles Avoidance

T. Tatehara, A. Nagahama and T. Wada

Learning methods to adapt the planned path to individual drivers have been proposed for automated driving systems (ADSs). However, existing methods could not apply the learning results in real-time for vehicle maneuvering. We propose on-demand online learning of preferred paths for individual drivers and investigate the comfort and trust after learning. Unlike the existing methods, the proposed ADS can apply the preferable learned path in real-time. Experimental results show that the proposed method improves the comfort and trust of drivers.

Unsupervised Scalable Multimodal Driving Anomaly Detection

Y. Qiu, T. Misu and C. Busso

This study proposes an unsupervised contrastive method using conditional generative adversarial networks (GAN) implemented with the attention model and the triplet loss function. Our approach trains conditional GANs to extract latent

features from modalities describing the vehicle's CAN-Bus signals, driver's physiological signals and distances to nearby pedestrians, vehicles and bicycles. An attention model combines the latent representations from the modalities. The framework is trained with the triplet loss function to generate effective representations to discriminate normal and abnormal driving segments.

An Intelligent Congestion Avoidance Mechanism Based on Generalized Regression Neural Network for Heterogeneous Vehicular Networks

F. Falahatraftar, S. Pierre and S. Chamberland

Considering self-adaptive and autonomous networking notions, a centralized and intelligent power adaptation technique is proposed to avoid data congestion in heterogeneous vehicular networks. Asystem model is designed to accurately predict network congestion and avoid it. This Machine Learning based approach could improve flexibility, reliability and stability of the network specifically when it confronts a data congestion situation.

Automated Data Transfer From ADAS to Android-Based IVI Domain Over SOME/IP

D. Kenjić, D. Živkov and M. Antić

Complexity of the evolving automotive system architecture led to the multiple implementations of the similar functionalities within different vehicle domains, and the redundancy of hardware resources. This article presents automated solution for exchanging both, software and hardware components data between ADAS and Android-based IVI domains over SOME/IP. The backbone of the generated solution enables the translation between commonly used interface definition languages - ARXML, FIDL, and AIDL, as well as the generation of the required cross-domain services and clients.

Integrity Management of the Reachable Space with Lane Grid Maps

C. Sanchez, P. Xu, P. Bonnifait and A. Armand

For an autonomous vehicle, reliable situation understanding is a key component of safe navigation. An incorrect prediction of an upcoming situation means that erroneous information may be supplied to the decision-making process, leading to hazardous outcomes. It is therefore of great importance to estimate the driving areas that are reachable by other interacting road users, without introducing misleading information. This paper presents a means of handling the integrity of prediction information, given the imperfection of object prediction, via a Lane Grid Map, that is to say a spatial representation of the situation at a tactical level, based on the topological layer of a high-definition map. We demonstrate experimentally, using real data, how the spatial sampling step of the grid representation can be used to manage the integrity of prediction information. Moreover, addressing interactions during the prediction makes it possible to handle some particular situations safely.

Multi-Hypothesis SLAM for Non-Static Environments With Reoccurring Landmarks

K. Nielsen and G. Hendeby

Based on a feature based multi-hypothesis map representation, a multi-hypothesis SLAM algorithm is developed inspired by target tracking theory. Both missed detections as well as false measurements are accounted for and rejected hypothesis are efficiently saved in the map representation to later be reactivated if the environment is changed back to an earlier state. This approach is in simulations proven to outperform state-of-the-art solutions in environments where moved landmarks are likely to reoccur in an earlier position.

II. Digital Twins and Parallel Intelligence for IVs

Digital twins and parallel intelligence (DTPI) play a significant role in the emerging development of intelligent vehicles (IV) and intelligent transportation systems (ITS). A digital twin is a digital replica of a physical object, system, or process, that can provide a unique means to achieve the cyber-physical integration. Through data-driven digitization technologies, the characteristics, behaviors, and relations in the physical world are digitized holistically to create high-fidelity virtual models. Under the framework, the virtual-real interactions, which is highly conjoined, coordinated, and integrated with human and social characteristics, have been steadily growing to be an emerging research focus.

The concept of parallel intelligence brings together the research developments from Artificial societies, Computational experiments, and Parallel execution, namely the ACP theory [2], [3], [4], and Cyber-Physical-Social Systems (CPSS)[5], [6] In this context, the emerging parallel driving and testing systems aim at enhancing intelligent driving capability and offering an ample solution for achieving a more intelligent transportation system, and ideally the Metaverse [9] in the future. Besides the existing development of DTPI and their applications in IV and ITS [10], humans (e.g., drivers [11]) would also play an important role in DTPI, contributing the social characteristics to DTPI as cyber-physical-social systems (CPSS) [12].

Along with the rapid growth of IEEE Transactions on Intelligent Vehicles since the beginning of 2022 [13], we shared a call for papers to the research community about a Special Issue (SI) on "*Digital Twins and Parallel Intelligence for Intelligent Vehicles and Intelligent Transportation Systems*", soliciting articles with the latest research and development advances in DTPI and their applications in IV and ITS. Among 81 submissions to this SI from researchers around the world, 18 top-quality articles were selected for final publication on our journal. Each of these 18 articles was peer-reviewed during the assessment process. The accepted articles cover a wide range of topics in the context of DTPI, including co-simulation, edge/cloud computing, resource allocation, cooperative driving, etc.

Based on the accepted articles of this SI, it can be envisioned that DTPI will play as an enabler for various research topics in the domains of IV and ITS, where the following insights can be derived:

- Given the extensive computational needs of processing Big Data in the digital space, advanced computing technologies such as edge computing and cloud computing will become increasingly crucial during the development of DTPI, where their associated research challenges such as data offloading and resource scheduling need to be tackled.
- Due to the high-fidelity nature of DTPI to replicate their physical counterparts, advanced simulation and testing environments will play an essential role in constructing and validating IV and ITS algorithms, which calls for the development and integration effort of various platforms considering multiple functionalities [14].
- The development of autonomous driving does not take human completely out of the loop, where human intervention is periodically required to guarantee vehicle safety on partially automated vehicles, and human passengers are the major customers for fully automated vehicles. Thus, human-centric DTPI need to be further studied that consider diverse preferences, habits, and other relevant human factors to improve ride comfort, acceptance to and trust on the autonomous driving technology from human drivers and passengers [15].
- Six types of IVs need to be studied and built in light of DTPI to drive our future societies smart (from "6V" to "6S"): Cognitive Vehicles and Parallel Vehicles for vehicular science and technology, Crypto Vehicles and Federated Vehicles for vehicular operation and management, and Social Vehicles and Ecological Vehicles for vehicular ethics and our sustainability, and these 6Vs would make our societies Safe in the physical world, Secure in the cyberworld, Sustainable in the ecological world, Sensitive to individual needs, Servable for all, and Smart in all [16].

III. Call for Participation: Decentralized Hybrid Workshops

At IEEE TIV we will continue to organize decentralized and hybrid workshops or symposia (DHW or DHS) on various issues in Intelligent Transportation Systems and Intelligent Vehicles.

Welcome to participate in our investigations on-line or off-line. Our discussions will be summarized and reported as perspectives, letters, or regular papers at IEEE TIV. We have organized several DHWs such as Verification and Validation (V&V) for intelligent vehicles, Autonomous Mining (AM), and Ethics, Responsibility, and Sustainability (ERS) for Carbon Neutrality [17], Sustainability for Transportation and Logistics (STL) and Data Science for Intelligent Vehicles (DSiV), any suggestions or proposals for future topics are greatly appreciated.

Looking forward to having you in our DHW or DHS.

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