Testing Intelligence: Accelerating the Verification and Validation of Intelligent Vehicles

Dear All,

Happy Chinese New Year of Rabbit to All of You.

According to the Chinese Calendar, 2023 is the Year of "Kui Mao (癸卯)", "Mao" happens to be the pronunciation of "cat" in Chinese, so this year is also the Year of Cat in Vietnam. Therefore, I would hope our journal to run as fast as a rabbit and be as elegant as a cat this year.

We would like to share with you the following news: By the end of January 2023, the tracking Journal Impact Factor of IEEE TIV has risen up to a record high of 6.677 according to the Web of Science. For this, I would like to express my sincere thanks for the great effort and enthusiastic dedication of all reviewers, associate editors, senior editors, and editorial staffs.

After an extensive discussion with many associate editors and senior editors, I would like to redefine our original "3-2-2-4" Guideline [1] as the new "**3-3-2-3**" Guideline for TIV's Manuscript Review Processes:

- **3** weeks for the first decision,
- **3** rounds of revision in maximum,
- **2** weeks for minor revisions,
- **3** weeks for major revisions.

With this guideline, we still expect a total 15-week review process for a submission.

This issue includes 2 letters and 77 regular papers. Both letters are resulted from our decentralized and hybrid workshops (DHW) [1], [2]: the first is from our DHW on Ethics, Responsibility, and Sustainability (ERS), the other from DHW on Autonomous Mining (AM).

This editorial is focused on Verification and Validation (V&V) for Intelligent Vehicles (IVs). At this point, we have already conducted 2 decentralized and hybrid symposia (DHS) and 3 DHWs on V&V. A Special Issue on "*Validation & Verification of Intelligent Vehicles*" has been announced last year [3]. After **the Scanning the Issue**, we will summarize the key points from our DHS and DHW in testing intelligence for accelerating the V&V of IVs.

I. Scanning the Issue

Driver Behavioral Cloning for Route Following in Autonomous Vehicles Using Task Knowledge Distillation

G. Li, Z. Ji, S. Li, X. Luo and X. Qu

Planning appropriate driving trajectory for route following is an important function for autonomous driving. Behavioral cloning, which allows automatic trajectory learning and improvement, has been effectively used in driving trajectory planning. However, existing behavioral cloning methods always rely on large scales of time-consuming, laborious, and reliable labels. To address this problem, this paper proposes a new off-policy imitation learning method for autonomous driving using task knowledge distillation. This novel method clones human driving behavior and effectively transfers the driving strategies to domain shift scenarios.

Accurate Pseudospectral Optimization of Nonlinear Model Predictive Control for High-Performance Motion Planning

G. Feng, Y. Han, S. E. Li, S. Xu and D. Dang

This paper presents two techniques to accelerate the numerical optimization of NMPC based motion planning. The Lagrange interpolation is adopted to discretize the state function of vehicle dynamics and the objective function and an adaptive strategy is designed to adjust the order of Lagrange polynomials based on the numerical analysis of discretization error. Moreover, a hybrid strategy is presented to construct the constraints for obstacle avoidance by combing the elliptic and linear time-varying ones together.

Milestones in Autonomous Driving and Intelligent Vehicles: Survey of Surveys

L. Chen, Y. Li, C. Huang, B. Li, Y. Xing, D. Tian, L. Li, Z. Hu, X. Na, Z. Li, S. Teng, C. Lv, J. Wang, D. Cao, N. Zheng and F.-Y. Wang

This paper proposes a survey of surveys for total technologies of autonomous driving and intelligent vehicles including the history, milestones, perspectives, ethics, and future research directions. To our knowledge, this article is the first survey of surveys with milestones in this field, which constitutes our complete research work together with two other technical surveys. We anticipate that this article will bring novel and diverse insights to researchers and abecedarians, and serve as a bridge between past and future.

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Blockchain-Oriented Privacy Protection of Sensitive Data in the Internet of Vehicles

C. Xu, H. Wu, H. Liu, W. Gu, Y. Li and D. Cao

This paper proposes a blockchain-based sensitive data privacy-protection scheme for vehicles connected to the Internet. The scheme establishes association rules for data mining, and creates a data security aggregation protocol as well as an end-to-end encryption mechanism. The privacy data protection in the Internet of Vehicles is achieved via static and dynamic strategies. The results show that the scheme provides higher hiding rate of sensitive data, shorter the key generation time and encryption time, and better encryption ability.

Evolutionary Utility Prediction Matrix-Based Mission Planning for Unmanned Aerial Vehicles in Complex Urban Environments

L. Xin, W. Yao, Y. Chen, J. Fu, D. Qu, C. Wu, J. Liu and G. Sun

An unmanned aerial vehicle (UAV) swarm that self-organizes to provide superior intelligence and overwhelming effects is a promising technology in urban scenarios. Complex terrain constraints of urban environment increase mission planning difficulties, and bring a strong input-output coupling between subproblems of mission planning, which affect the computing performance and effectiveness of the UAV swarm. In this paper, an evolutionary utility prediction matrix (EUPM) method is presented to solve the input-output-coupled mission planning problem for a UAV swarm executing heterogeneous tasks in an urban scenario with complex constraints. A structured framework of urban missions is established with a distributed mission planning architecture. The input-output coupling relationships between the subproblems of mission planning are analyzed in terms of typical urban mission patterns. Modules for the mission planning subproblems are designed with improved input-output coupling relationships. Simulations and hardware-in-loop experiments demonstrate that the EUPM method achieves accurate prediction of the utility and high effective mission planning solutions than the traditional methods.

Consensus Formation Control for Multiple AUV Systems Using Distributed Bioinspired Sliding Mode Control

T. Yan, Z. Xu and S. X. Yang

Consensus formation control of multiple autonomous underwater vehicles (AUVs) subject to nonlinear and uncertain dynamics is a challenging problem in robotics. To tackle this challenge, a distributed bioinspired sliding mode controller is proposed in this paper. First, the conventional sliding mode controller (SMC) is presented, and the consensus issue is considered on the basis of graph theory. Next, to tackle the high frequency chattering problem in SMC and meanwhile smooth the control behavior, a bioinspired approach is introduced, in which a neural dynamic model is employed to replace the nonlinear sign or saturation function in the synthesis of conventional SMC. Furthermore, the input-to-state stability of the resulting closed-loop system is guaranteed in the presence of external disturbances by the Lyapunov stability theory. Finally, simulation experiments are conducted to demonstrate the effectiveness of the proposed distributed formation control protocol.

Learning-Based Path Planning and Predictive Control for Autonomous Vehicles With Low-Cost Positioning

Z. Qi, T. Wang, J. Chen, D. Narang, Y. Wang and H. Yang

A path planning and control framework is developed for autonomous vehicles with low-cost positioning. For the path planning layer, a reinforcement learning agent is developed to generate a collision-free. For the control layer, a model predictive control based on vehicle dynamics is designed and a linear terminal constraint is considered. Simulation results demonstrate the effectiveness of the proposed algorithm when the positioning devices are imprecise.

Conflict Analysis for Cooperative Maneuvering With Status and Intent Sharing via V2X Communication

H. Wang, S. Avedisov, T. Molnar, A. H. Sakr, O. Altintas and G. Orosz

This paper establishes the concept of conflict analysis and demonstrates its applicability to aid the decision-making of vehicles at different levels of automation and cooperation. We study cooperative maneuvers under status sharing and intent sharing via vehicle-to-everything (V2X) communication. Conflict-free maneuvering strategies are developed and communication requirements for such strategies are determined. The results are demonstrated by both experimental data using real vehicles on a test track and simulations based on real highway data.

A Homography-Based Visual Servo Control Approach for an Underactuated Unmanned Aerial Vehicles in GPS-Denied Environments

H. Zhong, Y. Wang, Z. Miao, L. Li, S. Fan, and H. Zhang

A Homography-Based Visual Servo Control Approach for an Underactuated Unmanned Aerial Vehicles in GPS-Denied Environments. In this paper, the problem of stabilization control of an underactuated unmanned aerial vehicle based on the homography matrix in GPS-denied environments is addressed. A homography-based online translation velocity estimator and a nonlinear backstepping visual servo control approach are addressed to promote fast maneuvering without linear velocity feedback. Extensive simulation and experimental tests are carried out to verify the robustness and performance of the control approach. In addition, the autonomous tracking experiment when the target speed is unpredictable is also reported.

Evaluation of Thermal Imaging on Embedded GPU Platforms for Application in Vehicular Assistance Systems

M. A. Farooq, W. Shariff and P. Corcoran

The study is focused on evaluating the real-time performance of thermal object detection for smart vehicular systems by deploying DNN networks on GPU & single-board EDGE-GPU

computing platforms. Moreover, a novel large-scale C3I Thermal Automotive dataset comprising of $>$ 35000 distinct frames is acquired, processed, and open-sourced in challenging weather and environmental scenarios. State-of-the-art YOLO-v5 networks are trained using different public datasets as well as the newly acquired local dataset. Further network optimization boosts the FPS rate thus achieving a maximum 60 fps on Nvidia Xavier NX board.

Memory-Anticipation Strategy to Compensate Communication and Actuation Delays for Strings-Stable Platooning

Y. Zhang, Y. Bai, J. Hu, D. Cao and M. Wang

Cooperative Adaptive Cruise Control (CACC) has the potential to increase road. However, communication and actuation delays in CACC systems are detrimental to string stability. We design a memory-anticipation CACC that explicitly handles communication and actuation delays to fulfill string stability specifications. Our controller utilizes past information of the preceding vehicle (i.e., the memory) instead of its current state/control information to address communication delay, and a Smith predictor (i.e., the anticipation) to compensate for the actuation delay.

MetaScenario: A Framework for Driving Scenario Data Description, Storage and Indexing

C. Chang, D. Cao, L. Chen, K. Su, K. Su, Y. Su, F.-Y. Wang, J. Wang, P. Wang, J. Wei, G. Wu, X. Wu, H. Xu, N. Zheng and L. Li

In this paper, we propose MetaScenario, a framework for driving scenario data. We describe driving scenarios and design the unified data framework for the storage, processing, and indexing of scenario data based on relational database. The concept of atom scenario is proposed and characterized using semantic graphs. We also annotate behaviors and interactions of traffic participants in atom scenarios by extracting the spatiotemporal semantic evolution. MetaScenario can provide researchers with convenient tools for scenario data extraction and important analytical references.

GNN-PMB: A Simple but Effective Online 3D Multi-Object Tracker Without Bells and Whistles

J. Liu, L. Bai, Y. Xia, T. Huang, B. Zhu and Q.-L. Han

Multi-object tracking (MOT) is among crucial applications in modern advanced driver assistance systems (ADAS) and autonomous driving (AD) systems. The global nearest neighbor (GNN) filter, as the earliest random vector-based Bayesian tracking framework, has been adopted in most of state-of-the-arts trackers in the automotive industry. The development of random finite set (RFS) theory facilitates a mathematically rigorous treatment of the MOT problem, and different variants of RFS-based Bayesian filters have then been proposed. However, their effectiveness in the real ADAS and AD application is still an open problem. In this paper, it is demonstrated that the latest RFS-based Bayesian tracking framework could be superior to typical random vector-based Bayesian tracking framework via a systematic comparative study of both traditional random vector-based Bayesian filters with rule-based heuristic track maintenance and RFS-based Bayesian filters on the nuScenes validation dataset. An RFS-based tracker, namely Poisson multi-Bernoulli filter using the global nearest neighbor (GNN-PMB), is proposed to LiDAR-based MOT tasks. This GNN-PMB tracker is simple to use, and it achieves competitive results on the nuScenes dataset.

Eco-Driving of General Mixed Platoons With CAVs and HDVs

J. Yang, D. Zhao, J. Lan, S. Xue, W. Zhao, D. Tian, Q. Zhou and K. Song

Mixed vehicle platoons consisting of both connected and automated vehicles (CAVs) and human-driving (HDVs) will exist in traffic systems for a long period. This paper ropprop an eco-driving strategy for mixed platoons, composed of both offline planning an online tracking. In offline planning, an energy-efficient speed reference is determined through dynamic programming. In online tracking, model predictive controls (MPCs) are used to control the CAVs in real-time.

DRL-UTPS: DRL-Based Trajectory Planning for Unmanned Aerial Vehicles for Data Collection in Dynamic IoT Network

R. Liu, Z. Qu, G. Huang, M. Dong, T. Wang, S. Zhang and A. Liu

Using highly maneuverable Unmanned Aerial Vehicles (UAV) to collect data is a fast and efficient method that is widely studied. In most studies, they assume that the UAVs can obtain the location of the Cluster Head (CH) before take-off, allocate CHs, and optimize the trajectory in advance. However, in many real scenarios, many sensing devices are deployed in areas with no basic communication infrastructure or cannot communicate with the Internet due to emergencies such as disasters. In this kind of sensing network, the surviving devices often change, and the CHs cannot be known and allocated in advance, thus bringing new challenges to the efficient data collection of the networks by using UAVs. In this paper, a UAV path planning scheme for IoT networks based on reinforcement learning is proposed. It plans hover points for UAV by learning the historical location of CHs and maximizes the probability of meeting CHs and plans the shortest UAV path to visit all hover points by using the simulated annealing method. In addition, an algorithm to search for the location of CHs is proposed which is named Cluster-head Searching Algorithm with Autonomous Exploration Pattern (CHSA-AEP).

Group Vehicle Trajectory Prediction With Global Spatio-Temporal Graph

D. Xu, X. Shang, Y. Liu, H. Peng and H. Li

Vehicle trajectory prediction is a challenging problem in the field of autonomous driving, witch is of great significance to the safety of autonomous driving and traffic roads. In view of the interaction between surrounding vehicles and target vehicle and its own trajectory, we propose a new graph network model to predict future vehicle trajectory. First, the correlation network

of vehicles at each time is constructed based on the complex network method. In order to make up for the lack of real spatial relevance caused by the fixed graph, we propose an adaptive parameter matrix to coordinate and optimize the global spatio-temporal graph. Second, the global spatio-temporal features of vehicle historical trajectory data are extracted by stacked graph convolution module. Finally, the obtained graph features are coded based on seq2seq network, and the trajectory prediction of road vehicles at different times in the future is realized. Our model has been trained and verified on the published NGSIM US-101 and I-80 data sets.

Robust Performance-Prescribed Attitude Control of Foldable Wave-Energy Powered AUV Using Optimized Backstepping Technique

B. Dong, Y. Lu, W. Xie, L. Huang, W. Chen, Y. Yang and W. Zhang

The attitude control problem for a novel foldable wave-energy powered autonomous underwater vehicle is addressed. Through optimized backstepping framework and reinforcement learning technique, a robust performance-prescribed optimized backstepping control scheme is designed to find a trade-off between the controlaccuracy and control energy consumption. It is shown that the designed control scheme is energy-efficient and it is valuable for the application of ocean robots.

Distributed Cooperative Fault-Tolerant Control of High-Speed Trains With Input Saturation and Actuator Faults

L. Zhu, X. Li, D. Huang, H. Dong and L. Cai

This paper proposes a distributed adaptive fault-tolerant control approach for cooperative operation of high-speed trains under the framework of multi-agent system, which is effective to deal with the actuator failures, input constraints, unmodeled dynamics as well as external disturbances simultaneously. The convergence of the proposed controller is analyzed rigorously by applying the Lyapunov theorem, and the effectiveness is demonstrated by numerical simulations.

Adaptive Lane Change Trajectory Planning Scheme for Autonomous Vehicles Under Various Road Frictions and Vehicle Speeds

J. Hu, Y. Zhang and S. Rakheja

This paper proposes an adaptive lane change trajectory planning scheme to road friction and vehicle speed for autonomous driving, while considering both the maneuver safety and the comfort of occupants. In regard to achieve smooth trajectory, a 7th-order polynomial function is constructed to ensure continuity of the planned trajectory up to the derivative of the curvature (jerk). Unlike traditional planning methods that only consider very limited maneuvering conditions, the proposed scheme adapts to a wide range of road friction and vehicle speed, while ensuring enhanced occupants' ride comfort and acceptance. The proposed trajectory planning scheme creatively integrates all the dynamic constraints which are defined by road friction, safety, comfort and human-like driving style. It is shown that the proposed lane change planning algorithm reduces to the identification of exclusively the lane change duration given a constant forward speed. Illustrative simulation examples in MATLAB/Simulink have been conducted to demonstrate the validity of the proposed scheme.

Extended Object Tracking in Curvilinear Road Coordinates for Autonomous Driving

P. Dahal, S. Mentasti, S. Arrigoni, F. Braghin, M. Matteucci and F. Cheli

This paper proposes an Extended Object Tracking (EOT) algorithm based on Gaussian Mean Probability Hypothesis Density (GM-PHD) filter to perform extended track state estimation in Curvilinear Road Co-ordinates for Autonomous Driving. Fused measurements from Lidar and Radar sensors are used to perform object tracking. The proposed algorithm is validated through simulated and experimental data.

Energy-Efficient Driving in Connected Corridors via Minimum Principle Control: Vehicle-in-the-Loop Experimental Verification in Mixed Fleets

T. Ard, L. Guo, J. Han, Y. Jia, A. Vahidi and D. Karbowski

An optimal control is presented to conduct energy-efficient driving of an automated vehicle through a corridor of traffic lights with signal phase and timings known via connectivity. The algorithm is experimentally verified through vehicle-in-the-loop testing as integrated with traffic microsimulation software. Case studies are shown for traffic networks consisting of several mixtures of manual drivers and automated drivers together. Strong energy savings are demonstrated for both automated and manual drivers.

Coordinated Cooperative Distributed Decision-Making Using Synchronization of Local Plans

M. Kloock and B. Alrifaee

A cooperative decision-maker is developed that uses synchronization methods to achieve consistent plans among the agents. The algorithm uses parallel computations of the agents and iteratively converges to feasible solutions. To accelerate the convergence time, the algorithm modifies the coupling weights according to the solutions of each iteration. This paper proves the feasibility of this cooperative decision-making algorithm. Moreover, this paper shows the applicability of the cooperative decision-making algorithm in experiments using real-world car-like robots.

Integrated Satellite Multiple Two-Way Relay Networks: Secrecy Performance Under Multiple Eves and Vehicles With Non-Ideal Hardware

K. Guo, X. Li, M. Alazab, R. H. Jhaveri and K. An

In this paper, we study the secrecy performance for an integrated satellite multiple two-way terrestrial relay network, where the non-ideal hardware, multiple vehicle eavesdroppers and multiple legitimate vehicle users are applied in the considered networks. To derive better secrecy performance, opportunistic

terrestrial selection scheme is considered for the networks. Besides, the colluding eavesdropping scheme is also considered, where all the vehicle eaves work together to overhear the information. On these foundations, the closed-form expression for the secrecy outage probability is gotten. To obtain the further insights of system parameters and channel parameters in high signal-to-noise ratio regime, the asymptotic investigations for the secrecy outage probability is also investigated. At last, Monte Carlo results are given to show the efficiency and correctness of the analytical results.

Challenges of Driver Drowsiness Prediction: The Remaining Steps to Implementation

E. Perkins, C. Sitaula, M. Burke and F. Marzbanrad

Driver drowsiness has caused a large number of serious injuries and deaths on public roads and incurred billions of taxpayer dollars in costs. Hence, monitoring of drowsiness is critical to reduce this burden on society. This paper surveys the broad range of solutions proposed to address the challenges of driver drowsiness, and identifies the key steps required for successful implementation. Although some commercial products already exist, with vehicle-based methods most commonly implemented by automotive manufacturers, these systems may not have the level of accuracy required to properly predict and monitor drowsiness. State-of-the-art models use physiological, behavioural and vehicle-based methods to detect drowsiness, with hybrid methods emerging as a superior approach. Current setbacks to implementing these methods include late detection, intrusiveness and subject diversity. In particular, physiological monitoring methods such as Electroencephalography (EEG) are intrusive to drivers; while behavioural monitoring is least robust, affected by external factors such as lighting, as well as being subject to privacy concerns.

Interaction-Aware Decision-Making for Automated Vehicles Using Social Value Orientation

L. Crosato, H. P. H. Shum, E. S. L. Ho and C. Wei

To tackle the problem of decision-making in the presence of pedestrians, we introduced a framework based on Social Value Orientation and Deep Reinforcement Learning (DRL) that is capable of generating decision-making policies with different driving styles. The policy is trained using state-of-the-art DRL algorithms in a simulated environment. A novel computationally-efficient pedestrian model that is suitable for DRL training is introduced. Simulation results show how the developed model exhibits natural driving behaviours, such as short-stopping, to facilitate the pedestrian's crossing.

A Systematic Literature Review on Automotive Digital Forensics: Challenges, Technical Solutions and Data Collection

K. Strandberg, N. Nowdehi and T. Olovsson

Our work is the first systematic literature review on automotive digital forensics. We discuss the existing challenges, technical solutions, and data collection methods and tools. Over 300 papers published between 2006 and 2021 are identified and assessed. Forensically relevant data are mapped into different categories, required security properties, and potential stakeholders. The contributions of this paper can be utilized by digital forensic investigations in automotive and similar areas, facilitate further research, and serve as guidelines for engineers implementing forensics mechanisms.

Trajectory Tracking of Autonomous Vehicle: A Differential Flatness Approach With Disturbance-Observer-Based Control

W. Sun and X. Wang

This paper proposes a novel integrated control scheme for trajectory following of autonomous vehicle in the presence of the nonlinearity and coupling motions. A kinodynamic vehicle model is established for trajectory tracking and then, derived from the elaborate selection of flat outputs, its differential flatness property is proved. To promote the tracking precision, a flatness disturbance-observer-based controller is designed based on the flatness property. The performance of the proposed approach is given and discussed.

Autonomous Driving Policy Continual Learning With One-Shot Disengagement Case

Z. Cao, X. Li, K. Jiang, W. Zhou, X. Liu, N. Deng and D. Yang

Disengagement cases are rare but valuable for autonomous driving, since they directly reflect the defects of current policy. This work aims to automatically learn from the one-shot disengagement case to perform better in this case. It provides a possible way to make autonomous vehicles continually improve during road testing without manual adjustment. The evaluation results show that the proposed DICL agent can get improvement with a one-shot disengagement case, outperforming the SAC RL agent.

Engine Fuel Consumption Modelling Using Prediction Error Identification and On-Road Data

A. K. Madhusudhanan, X. Na, D. Ainalis and D. Cebon

Engine modelling is an important step in predicting a vehicle's fuel consumption. Most methods in the literature require dedicated tests on a test track or on a chassis dynamometer or measurements from several days of vehicle operation. This article proposes a new method to model fuel flow rate of a diesel engine and a compressed gas engine using prediction error identification and on-road data collection. The proposed method is applicable for other types of vehicles, including electric vehicles.

Hierarchical Velocity Control Considering Traffic Signal Timings for Connected Vehicles

L. Guo, H. Chu, J. Ye, B. Gao and H. Chen

A hierarchical velocity control system considering different drive preferences for connected and automated vehicles is proposed to improve overall efficiency under the vehicle-to-X

environment. A control-oriented task planning in multiple road segments is formulated, which is amiable to numerical computation and can consider different drive preferences. Simulation results indicate that energy-saving and computational efficiency are improved using the proposed control system. The solution algorithm is further demonstrated under a hardware-in-the-loop simulation.

Ideal Reference Point in Planning and Control for Automated Car-Like Vehicles

C. Popp, C. Ziegler, M. Sippel and H. Winner

The position of the reference point affects the vehicle's driving behavior and is defined to be ideal if the needed lane width on the left and right side of the planned path is the same. After analytical derivation of the ideal position, a simple collision check is presented as an exemplary application that benefits from the selected reference point. In addition, the influence on a lateral feed-forward controller is investigated.

Siting and Sizing Charging Infrastructure for Electric Vehicles With Coordinated Recharging

S. Schoenberg, D. S. Buse and F. Dressler

The popularity of electric vehicles is increasing, but the public charging infrastructure is still insufficient. To reduce extra time spent with charging on everyday trips, we introduce a new charging infrastructure siting and sizing approach. We analyze daily schedules of drivers to find suitable locations for slow and fast charging stations. In simulation, we test how many charge points to assign to each charging station. Vehicles can be charged with either en-route or destination charging using a realistic model for charging and energy consumption for five electric vehicle models of different car segments. To reduce waiting times at charging stations, we use a centralized charging station database (CSDB), that coordinates charging between vehicles. We found that a combination of a few centralized fast charging stations and many distributed slow charging stations is the best option to improve the average extra time spent with charging for all vehicle types. We also found that by using the CSDB to coordinate charging between vehicles, we were able to significantly reduce the necessary number of charge points to achieve an acceptable average extra time.

Global Perception-Based Robust Parking Space Detection Using a Low-Cost Camera

L. Wang, X. Zhang, W. Zeng, W. Liu, L. Yang, J. Li and H. Liu

Parking space detection can help car owners save time in finding parking spaces. We present a visual detection method to reduce the cost. We propose a Global Perceptual Feature Extractor (GPFE) module, which can be combined with the existing network to improve the performance. The GPFE module utilizes the transformer encoder to extract global features and designs the classification attention module to pay more attention to channel information. Experiments show that GPFE can improve the accuracy of existing networks significantly.

Hybrid State Observer Design for Estimating the Hitch Angles of Tractor-Multi Unit Trailer

S. Han, K. Yoon, G. Park and K. Huh

In this paper, for the tractor with two articulated trailers, a novel estimation system for the hitch angles is introduced by combining the Kalman filter with the deep learning network and transfer function techniques. The Gated Recurrent Unit (GRU) network and the transfer function models are constructed to calculate the hitch angles, respectively, as the virtual measurement. These virtual measurements from the two methods are integrated separately into the Kalman filter design to improve the estimation performance.

Detecting Darting Out Pedestrians With Occlusion Aware Sensor Fusion of Radar and Stereo Camera

A. Palffy, J. F. P. Kooij and D. M. Gavrila

Early detection of crossing pedestrians is crucial in automated driving. However, this is often difficult in urban scenarios where pedestrians are often occluded (not visible) behind objects, e.g., parked vehicles. We propose an occlusion aware fusion of stereo camera and radar sensors to address such scenarios, which can save up to 0.26 s in reaction time.

Location-Guided LiDAR-Based Panoptic Segmentation for Autonomous Driving

G. Xian, C. Ji, L. Zhou, G. Chen, J. Zhang, B. Li, X. Xue and J. Pu

The application of artificial intelligence in autonomous driving is becoming increasingly extensive. LiDAR-based 3D point cloud panoptic segmentation is one of the most promising and arduous tasks. Although recent methods have produced promising results, most of them ignore the prior distribution of objects in the 3D point clouds. In this paper, we first investigate the distribution of objects around the heading of vehicles and observe that several objects are severely biased. On the basis of this observation, we use the bird's eye view (BEV) representation to project the 3D point clouds into a 2D image and divide the BEV projection into eight areas. For each area, we apply input-dependent convolution kernels to extract the local feature. These local features are concatenated to the panoptic backbone for panoptic segmentation.

A Crowd-Aided Vehicular Hybrid Sensing Framework for Intelligent Transportation Systems

Z. Zhu, Y. Zhao, B. Chen, S. Qiu, Z.Liu, K. Xie and L. Ma

Based on the development of social transportation and social sensing, a crowd-aided vehicular hybrid sensing framework is designed for the first time, which blends numerous mobile devices and individuals in a unified target. The framework assigns sensing tasks to dedicated sensing vehicles and mobile users effectively and achieves improved inference results in unsensed subareas. Research findings reveal that our hybrid

sensing framework enhances the data collection at a low-cost manner for intelligent transportation systems.

Event-Triggered Multi-Lane Fusion Control for 2-D Vehicle Platoon Systems With Distance Constraints

Z. Zhou, F. Zhu, D. Xu, B. Chen, S. Guo and Y. Dai

A fixed time control scheme for 2-D vehicle platoon is presented to ensure the distance constraints when performing multi-lane fusion. Moreover, to offset the impacts of the unknown system dynamics and the external disturbances, an unknown input reconstruction method with asymptotic convergence is developed by utilizing the interval observer technique. The corresponding simulation results also verify the effectiveness of the proposed strategy.

Mixed-Integer and Conditional Trajectory Planning for an Autonomous Mining Truck in Loading/Dumping Scenarios: A Global Optimization Approach

B. Li, Y. Ouyang, X. Li, D. Cao, T. Zhang and Y. Wang

An optimization-based trajectory planner is proposed for a heavy-duty mining truck near the loading/dumping sites of an open-pit mine. The concerned task is difficult due to the unstructured environment, complex vehicle kinematics, and task-related regulations. These factors make the concerned task a mixed-integer nonlinear program (MINLP) incorporated with conditional constraints (denoted as C-MINLP). Instead of solving the C-MINLP directly, we propose a coarse-to-fine framework so that the coupled difficulties are divided and conquered quickly.

Bridging View Disparity Between Radar and Camera Features for Multi-Modal Fusion 3D Object Detection

T. Zhou, J. Chen, Y. Shi, K. Jiang, M. Yang and D. Yang

This paper proposes a radar-camera feature fusion 3D object detection method called RCBEV. RCBEV bridges the view disparity between multi-modal features, enhances the information interaction during fusion course, and realizes an efficient perception system under the top-down view. The experimental results on the large-scale benchmark nuScenes show that the proposed algorithm provides precise and robust detections compared with the baseline methods for autonomous driving.

ACP-Based Modeling of the Parallel Vehicular Crowd Sensing System: Framework, Components and an Application Example

Y. Ren, H. Jiang, X. Feng, Y. Zhao, R. Liu and H. Yu

To enhance the generality and robustness of the vehicular crowd sensing (VCS) system, the authors introduce the ACP-based parallel intelligence into its life-cycle, and develop a novel framework called parallel VCS (P-VCS). In this article, the structure and components of P-VCS are described detailedly. In addition, the authors also provide an application example to demonstrate how P-VCS can cope with the complexity of social dimensions and optimize the decision-making process in the physical VCS.

Bi-Unet: A Dual Stream Lightweight Network for Real-Time Highway Surface Segmentation

J. Sun, J. Shen, X. Wang, Z. Mao and J. Ren

A dual-stream lightweight network for real-time and all-day highway surface segmentation is proposed. An efficient Light-Shuffle module and Road Attention Network are presented. Meanwhile, the segment performance of the remote end of the highway is also analyzed. The efficiency and accuracy of the proposed model are validated in our proposed high-quality real-world highway surface dataset.

Attention-Based Interrelation Modeling for Explainable Automated Driving

Z. Zhang, R. Tian, R. Sherony, J. Domeyer and Z. Ding

An explainable algorithm is proposed to support the decision-making and transparency of automated driving systems by providing multi-modal explanations, especially when interacting with pedestrians. The proposed algorithm combines global visual features and traffic object interrelation features via self-constructed graphs. In addition, an attention-based module helps make driving decisions with semantic explanations of the reasoning. The performance surpasses state-of-the-art algorithms in two benchmark datasets.

A Survey on Map-Based Localization Techniques for Autonomous Vehicles

A. Chalvatzaras, I. Pratikakis and A. A. Amanatiadis

In this survey, the current landscape of centi-meter level localization accuracy for autonomous vehicles is discussed. High-definition maps are improved continuously allowing recent algorithms to leverage the advantages that these maps offer. This survey offers up-to-date insights into the recent progress of HD maps, sensors, datasets and localization algorithms. All surveyed works are discussed and accompanied by the used sensors, the utilized map layers, their experimental environments and their reported accuracy for providing the necessary intuitions for optimal system design.

Hy-Seg: A Hybrid Method for Ground Segmentation Using Point Clouds

Y. Qian, X. Wang, Z. Chen, C. Wang and M. Yang

Hy-Seg is a hybrid method and achieves accurate and fast ground segmentation. The 3D point cloud generated by LIDAR is represented by a polar grid map. Then, candidate ground points in each grid are generated by a gradient-based method. Finally, the original 3D point cloud is segmented using the fitted model. Experiments show that the proposed method can not only achieve an accurate segmentation result but also run at a frequency of 53 Hz.

Hierarchical Estimation-Based LiDAR Odometry With Scan-to-Map Matching and Fixed-Lag Smoothing

Z. Cao, S. Liang, C. Wang and J. Yu

A hierarchical LiDAR odometry framework HELO is proposed to reduce the accumulated error of pose estimation via combining the low-level scan-to-map matching and the high-level fixed-lag smoothing. The feature-centric feature management and one-to-many measurement residual model are designed to make our system efficient and accurate. The effectiveness of the proposed HELO is verified on the datasets and an actual scenario.

Multi-Vehicle Conflict Management With Status and Intent Sharing Under Time Delays

H. M. Wang, S. S. Avedisov, O. Altintas and G. Orosz

This paper discusses conflict analysis for multiple vehicles possessing different automation levels. Two different classes of cooperation, enabled by vehicle-to-everything (V2X) communication, are considered: status-sharing and intent-sharing. Our analysis considers two types of time delays, one in vehicle dynamics and the other in V2X communication. We quantify the effects of time delays in a mixed-autonomy traffic environment and unveil the benefits of intent information. Real highway data-based simulations are used to validate the extended conflict management framework.

Integrated Graphical Representation of Highway Scenarios to Improve Trajectory Prediction of Surrounding Vehicles

L. Hou, S. E. Li, B. Yang, Z. Wang and K. Nakano

Varying numbers and types of vehicles, various road structures and traffic rules bring difficulties to an autonomous vehicle driving in highway traffic scenarios. It is important to simultaneously consider all these elements in an integrated framework when predicting the future trajectories of surrounding vehicles. This paper presents a unified graphical representation method for dynamic traffic scenarios based on integrating not only the constraints from vehicles but also the collision risk implied behind road structures and traffic rules. Different from previous studies which ignores road structures and traffic rules or separately represent them in a qualitative way, this method can make better use of the influences of these environment elements in a quantitative way to improve trajectory prediction of surrounding vehicles in highway scenarios.

DeepStep: Direct Detection of Walking Pedestrian From Motion by a Vehicle Camera

M. Kilicarslan and J. Y. Zheng

The problem of walking pedestrian detection in the spatial-temporal domain is investigated. A walking pedestrian detection system using a one-stage deep learning model in the spatial-temporal domain is proposed and implemented. The proposed method reached good accuracy in a publicly available dataset and showed a significant speed-up for real-time processing, which is suitable for safety-critical pedestrian detection in driving videos.

Toward Safe and Efficient Human–Swarm Collaboration: A Hierarchical Multi-Agent Pickup and Delivery Framework

X. Gong, T. Wang, T. Huang and Y. Cui

Multi-agent pickup and delivery (MAPD) is crucial in intelligent storage systems (ISSs), where multiple automated guided vehicles (AGVs) are assigned to various and potentially uncertain dynamic tasks. In this work, we consider a humanswarm hybrid system consisting of human workers and a swarm of AGVs collaborating to accomplish MAPD tasks. A humanswarm hybrid system pickup and delivery ((HS)2PD) framework based on the receding-horizon prediction window is proposed, which facilities the development of future ISSs. This (HS)2PD framework is essentially a two-layer hierarchical decision procedure, which takes the uncertainties of human behavior and the dynamic changes of tasks into account. The first layer is a two-level programming model handling the problems of mode assignment and task allocation. The second layer calculates each vehicles exact path by solving mixed-integer programmings. An integrated high-efficient algorithm for the (HS)2PD problem is also proposed. The practicality and validity of the above algorithm are demonstrated via several groups of numerical simulations of (HS)2PD tasks.

Secrecy Performance for RIS-Based Integrated Satellite Vehicle Networks With a UAV Relay and MRC Eavesdropping

F. Zhou, X. Li, M. Alazab, R. H. Jhaveri and K. Guo

This work investigates the secrecy issues for the secrecy reconfigurable intelligent surface-based integrated satellite unmanned aerial vehicle (UAV) relay networks with multiple vehicle eavesdroppers. Particularly, the maximal ratio combining (MRC) eavesdropping is utilized to overhear the legitimate signal information. The UAV is applied to forward the legitimate signal to the destination user. Reconfigurable intelligent surface is applied to ensure the transmission. Relied on the proposed secrecy system model and MRC eavesdropping scheme, this paper gets the detailed investigations for the secrecy outage probability (SOP) through the whole signal-to-noise ratios (SNRs) to valuate the effects of important parameters on the SOP. Moreover, to achieve the further impacts of main parameters on the SOP at high SNRs, the approximate analysis for the SOP is also gotten together with the secrecy diversity order (SDO) and secrecy coding gain (SCG). At last, several typical Monte Carlo (MC) results are obtained to present the rightness of obtained theoretical analysis.

An ML-Aided Reinforcement Learning Approach for Challenging Vehicle Maneuvers

D. C. Selvaraj, S. Hegde, N. Amati, F. Deflorio and C. F. Chiasserini

We propose a Deep Reinforcement Learning (DRL) based data-driven cooperative Adaptive Cruise Control application to handle challenging vehicle maneuvers such as cut-in and cut-out. Specifically, we envision a 2-Layer Learning Cooperative ACC (2LL-CACC) that accounts for all the relevant factors, namely, passengers' safety and comfort and road traffic efficiency, to manage challenging maneuvers effectively. Subsequently, we

evaluate the performance of the proposed scheme through the CoMoVe simulation framework and further validate it through a hardware-in-the-loop implementation.

Performance and Challenges of 3D Object Detection Methods in Complex Scenes for Autonomous Driving

K. Wang, T. Zhou, X. Li and F. Ren

How to ensure robust and accurate 3D object detection under various environment is essential for autonomous driving (AD) environment perception. While, until now, most of the existing 3D object detection methods are based on the ordinary driving scenes provided by the mainstream dataset. The researches on actual complex scenes (adverse illumination, inclement weather, distant or small objects, etc.) have been ignored and there is still no comprehensive review of the recent progress in this field. Thence, this paper aims to gain a deep insight on the performance and challenges of 3D object detection methods under complex scenes for AD. Firstly, we discuss the complex driving environments in actual and the perception limitations of mainstream sensors (LIDAR and camera). Then we analyze the performance and challenges of single-modality 3D object detection methods. Therefore, in order to improve the accuracy and robustness of 3D object detection methods in some complex AD scenes, the fusion of L-C (LIDAR-camera) is recommended and systematically analyzed. Finally, some suitable datasets and potential directions are comparatively summarized to support the relative research in complex driving scenes. We hope that this review could facilitate people's research and look forward to more progress in this timely and crucial problem field.

Falsifying Motion Plans of Autonomous Vehicles With Abstractly Specified Traffic Scenarios

M. Klischat and M. Althoff

A method to synthesize traffic scenarios for efficiently falsifying motion planning algorithms of autonomous vehicles is proposed. Using Monte-Carlo tree search, falsifying trajectories of other traffic participants are searched within their reachable sets that comply with the abstractly defined traffic scenarios. The method enables considering complex maneuvers of multiple vehicles and additional failure specifications. The efficiency and success rate of the falsification algorithm is evaluated in several scenarios.

Model-Free Cluster Formation Control of NMSVs With Bounded Inputs: A Predefined-Time Estimator-Based Approach

C.-D. Liang, M.-F. Ge, Z.-W. Liu, L. Wang and J. H. Park

Facing the cluster formation problem of the networked marine surface vehicles (NMSVs), a predefined-time estimator-based hierarchical control algorithm is designed in a bounded way and without prior model information. By employing the proposed scheme, the considered problem can be decomposed into two subcontrol problems, which are respectively addressed by the designed predefined-time estimator and the local tracking controller. The correctness of the main results is verified by the simulation results.

Learning-Based Synthesis of Robust Linear Time-Invariant Controllers

M.-A. Beaudoin and B. Boulet

This article introduces a learning-based synthesis method for robust linear time-invariant vehicle controllers. The method combines a robust control framework with gradient-based parameter optimisation. It allows to train LTI controllers on any learned model of vehicle dynamics, while maintaining robust stability guarantees. The method is demonstrated on simulated lane-change manoeuvres with concurrent vehicle acceleration.

Love of Variety-Based Latency Analysis for High Definition Map Updating: Age of Information and Distributional Robust Perspectives

D. Chen, Y. Zhu, D. Wang, H. Wang, J. Xie, X.-P. Zhang and Z. Han

This work jointly considers the generation and transmission process of high-definition (HD) map with a low-latency purpose. A layered HD map is introduced, and a love-of-variety-based method is proposed to mathematically model the HD map. Besides, solutions are derived for deterministic and uncertain edge computing resources cases, respectively, regarding a layer-wise HD map transmission. Simulation results show the proposed method is effective and valuable for the low-latency application, like HD map transmission.

Stop-Line-Aided Cooperative Positioning for Connected Vehicles

X. Wang, C. Jiang, S. Sheng and Y. Xu

A stop-line-aided cooperative positioning framework for connected vehicles in intersection scenarios via Vehicle-to-Vehicle communication is proposed. Firstly, a self-positioning correction scheme for the first stopped vehicle is presented. Then, the benefits of the first stopped vehicle are extended to the whole vehicular ad-hoc network via the designed cooperative inertial navigation framework. Experiments in Beijing show the effectiveness of the proposed stop-line-aided cooperative positioning framework.

POMDP Motion Planning Algorithm Based on Multi- Modal Driving Intention

L. Li, W. Zhao, C. Wang and Z. Luan

On highways, the interaction with surrounding vehicles is very crucial for the decision-making and planning of autonomous vehicles. However, the multi-modal driving intentions of surrounding vehicles have brought great challenges. Aiming at the multi-modal driving intention of surrounding vehicles, a multi-modal driving risk field based on dynamic collision region is proposed, and MDI-POMDP decision framework is established, which integrating behavior decision and motion planning. Firstly, the multi-modal probability distribution of driving intention is fused to establish a driving risk field. Moreover, combined with the longitudinal safety distance model and lateral driving direction, the concept of dynamic collision area is proposed in the driving

risk field. Then, MDI-POMDP is formulated to analyze the influence of the uncertainty on planning, which is caused by the multi-modal driving intention of surrounding vehicles. In the following, with the help of the previous state, a time-dependent DRL algorithm RDPG is designed to enhance the current observation, to solve the optimal driving policy under partial observation and generate the optimal trajectory. Furthermore, the simulation results show that the performance of our proposed motion planning algorithm is outstanding, compared with the states-of-the-art methods. And our algorithm has the powerful ability to model the multi-modality of driving intention, to ensure the traffic safety.

Design and Implementation of Proximal Planning and Control of an Unmanned Ground Vehicle to Operate in Dynamic Environments

S. Khan and J. Guivant

This paper presents a novel proximal planning and control (PPC) formulation for an unmanned ground vehicle (UGV) which is affected by skidding and slip disturbances. The control approach also considers the presence of moving and static obstacles in the context of operation. The PPC technique is divided into three parts; first, a nonlinear model predictive control (NMPC) based path-planner is designed to periodically generate an updated feasible trajectory for reaching the goal pose, under the constraint of avoiding collisions with dynamic and static objects which are present in the context. In particular, a proximal averaged Newton-type method for optimal control (PANOC) is used to implement NMPC. Second, the velocity commands are produced via evolutionary programming (EP) based on kinematic control (KC). Third, a dynamic control process with an extended state observer (ESO) is introduced to estimate disturbances whose magnitudes are unknown but bounded. Finally, to verify the performance of the proposed scheme, simulations are performed for the platform operating in the presence of static obstacles (SO) and moving obstacles (MO), whose trajectories may be nonlinear and difficult to be accurately predicted. Additionally, we have investigated and confirmed that the proposed PPC is able to operate in real time under limited CPU processing resources.

Second-Order Statistics for IRS-Assisted Multiuser Vehicular Network With Co-Channel Interference

Girdher, A. Bansal and A. Dubey

A downlink multi-user intelligent reflecting surface (IRS)-assisted vehicular communication system is considered employing OFDMA scheme. The performance of the considered system is evaluated in terms of second-order statistics in the presence of multiple co-channel interferers. In particular, we develop analytical expressions of level crossing rate, average outage duration packet-error-rate and throughput. The impact of various parameters, such as number of reflecting elements of IRS, minimum reflection amplitude, number of co-channel interferers, and Doppler shift has been investigated on the system's performance.

Gaze Control for Active Visual SLAM via Panoramic Cost Map

X. Yuwen, H. Zhang, F. Yan and L. Chen

This paper focuses on improving the positioning accuracy of the visual simultaneous localization and mapping (VSLAM) through actively controlling the gaze of the positioning camera mounted on an autonomous mobile robot. We present a gaze control method for the VSLAM with a novel panoramic cost map. In the method, we add a panoramic camera besides the positioning camera to aid the gaze control of the positioning camera. The panoramic camera is modeled as a unit sphere model and the positioning camera is modeled as a pinhole model that is concentric with the unit sphere model. The panoramic camera captures a panoramic image for the evaluation of an environment. The effective factors, such as feature points and moving objectives, of the VSLAM are detected in the panoramic image. When the pinhole model pointing at a specific orientation, a cost value can be calculated according to the effective factors. After calculating the above-mentioned cost in all available orientations of the pinhole model, a panoramic cost map that is determined by the individual costs can be established. Next, a target orientation is selected according to the panoramic cost map and the positioning camera is rotated to the target orientation by a pan-tilt. The test results in different scenery show that the proposed method can improve the positioning accuracy of the VSLAM compared to stationary orientation.

High Speed Emulation in a Vehicle-in-the-Loop Driving Simulator

E. Weiss and J. Gerdes

A method for immersing drivers in high speed conditions using virtual reality on a four-wheel steer-by-wire test vehicle is presented. The proposed approach provides drivers with visual, vestibular, and haptic feedback corresponding to the dynamics of a vehicle moving at 2-3 times the speed of the test vehicle. Experiments demonstrate the effectiveness of this method through objective performance metrics and comparison to equivalent tests driven manually for a variety of relevant maneuvers.

Encouraging Validatable Features in Machine Learning-Based Highly Automated Driving Functions

De Candido, M. Koller and W. Utschick

As more Highly Automated Driving (HAD) functions are implemented using Machine Learning (ML)-based methods, the challenge of validating them is undeniable. In a prior work, we proposed a validation method which analyzes the feature embeddings of Deep Neural Network (DNN) classifiers. Using this method, if different DNNs with similar classification performance are given, an engineer can inspect the feature embeddings and choose the DNN showing the most meaningful embeddings. This is a form of validation of the chosen architecture. In our prior work, the feature embeddings were passively observed with the goal of choosing the architecture with the most meaningful embeddings. In this work, we modify the DNN loss function

in order to encourage more meaningful feature embeddings, aiming to actively strengthen the validation of a given DNN architecture. To this end, we make use of kmeans friendly spaces, introduced in the context of autoencoders. We argue that these lead to desirable feature embeddings for validation. Furthermore, we introduce two classification rejection rules, which can be used to reject certain classifications. This increases the overall performance of the ML-based method. Ultimately, these rejection rules positively benefit from the k-means friendly space. We use a lane change prediction task as a safety-critical HAD function use-case throughout the paper. We show that the proposed methods can be used on a wide range of ML-based algorithms.

Exploiting Linear Structure for Precision Control of Highly Nonlinear Vehicle Dynamics

M. T. Peterson, T. Goel and J. C. Gerdes

Drifting—operating a vehicle at a high sideslip angle—offers intriguing possibilities for controlling autonomous vehicles in critical situations. Previous approaches to path tracking while drifting relied on nonlinear vehicle models. However, we demonstrate that linearized models capture the necessary dynamics for control in a large region about a drift equilibrium. Using this linearized model, we develop and implement a controller on MARTY, an electric DMC DeLorean, and track equilibrium and quasi-equilibrium paths with centimeter-level accuracy that exceeds prior work.

The Stanford Drone Dataset Is More Complex Than We Think: An Analysis of Key Characteristics

J. J. Andle, N. Soucy, S. Socolow and S. Yasaei Sekeh

Characterizes the Stanford Drone Dataset (SDD). Despite the SDD's common use, a thorough analysis of its characteristics is lacking. The layout of the videos within the dataset, the impact f preprocessing the data, and the effects of the class distribution on a trained model's ability to generalize to similar datasets are thoroughly described. This investigation is done by implementing a custom measure for visualization of interactions, utilizing existing trajectory prediction models, and comparing to the similar intersection Drone (inD) Dataset

Distributed-Observer-Based Distributed Control Law for Affine Nonlinear Systems and Its Application on Interconnected Cruise Control of Intelligent Vehicles

H. Xu, S. Liu, B. Wang and J. Wang

Distributed-observer-based distributed control law for interconnected systems is developed for a class of affine nonlinear systems. To this end, we overcome the difficulty of proving the joint observability and the absence of separation principle of distributed observer for nonlinear systems. The asymptotic omniscience of distributedobserver and the stability of closed-loop systems are successfully proved. And the performance of the proposed distributed control law is shown to be resembled to the centralized control. The automated highway system is employed to be verified the developed results.

Safe and Stable RL (S2RL) Driving Policies Using Control Barrier and Control Lyapunov Functions

B. Gangopadhyay, P. Dasgupta and S. Dey

Deep Reinforcement Learning (DRL) has been successfully applied to learn policies for safety-critical systems with unknown model dynamics in simulation. DRL controllers though optimal in terms of reward, do not provide any safety and stability guarantees. With reliance on model information, safety conditions can be expressed as Control Barrier Functions (CBFs) and performance objectives can be expressed as Control Lyapunov Functions (CLFs) for real-time optimization-based controllers. In this work, we use an amalgamation of model-free RL and model-based controllers to establish safety and stability. We first design CLF, CBF Quadratic Programs (QPs) for different driving manoeuvres on nominal vehicle dynamics. Reinforcement Learning (RL) agents are trained to learn policies for the actual vehicle with enhanced dynamics. In order to incorporate safety and stability while retaining optimal behaviour we selectively guide the RL agents using CLF, CBF QPs. This results in both safe and stable (S2 RL) policies. We empirically validate the proposed methodology on different driving manoeuvres.

Autonomous Lateral Maneuvers for Self-Driving Vehicles in Complex Traffic Environment

Z. Li, J. Jiang, W.-H. Chen and L. Sun

This paper proposes a Model Predictive Control based method to generate a safe and feasible trajectory for the ego vehicle to perform various lateral manoeuvres in complex traffic environment. A reference speed generation function is proposed to automatically adjust the position of the ego vehicle. In addition, a decision-making framework is designed to automatically start or stop the lateral manoeuvre. The simulation results show that various manoeuvres can be successfully achieved with the proposed algorithm.

E-LOAM: LiDAR Odometry and Mapping With Expanded Local Structural Information

H. Guo, J. Zhu and Y. Chen

This paper presents E-LOAM (LiDAR Odometry and Mapping with Expanded Local Structural Information), which expands the feature points with local structural information and augments the feature space with intensity-related features. E-LOAM is able to capture more information for LiDAR odometry and mapping. Experimental results with both KITTI odometry datasets and self-collected real-world datasets, demonstrate the efficacy and efficiency of E-LOAM.

Automotive Radar-Based Hitch Angle Tracking Technique for Trailer Backup Assistant Systems

M. Bahramgiri, S. Nooshabadi, K. Olutomilayo and D. Fuhrmann

We propose a technique for trailer angle detection (TAD) for use in advanced trailer backup assistance system (TBAS) for semi-autonomous or full-autonomous backup maneuver. TBAS incorporates a combined trailer-tow-vehicle kinematic model,

which is requires an estimate of the hitch angle. The proposed radar-based TAD model, for the estimate of the hitch angle, processes reflections acquired from the mmWave radars situated at the rear side of the vehicle, to detect the trailer and track its orientation in relation to the tow-vehicle. This technique is based on the tracking of individual points in the merged radars point-cloud. Each tracked point is considered as a hitch angle estimator. Using the current and past position information of a point, the model estimates the current hitch angle. To offer an accurate and reliable estimation for the hitch angle, the model fuses the estimated hitch angle by all estimators, as well as the yaw rate of the vehicle. To track each individual radar point, the model employs the extended Kalman filter, which is robust to the noisy radar measurements. In the presence of strong and persistence reflections from the trailer, the model can track the trailer successfully and return the hitch angle with a reliability measure equal to 90%.

Gated Adversarial Network Based Environmental Enhancement Method for Driving Safety Under Adverse Weather Conditions

K. Wang, L. Pu, J. Zhang and J. Lu

The adverse weather conditions have brought considerable difficulties in vision-based applications, which are closely related to the driving safety of autonomous vehicles. However, to date, the greater part of the existing environmental perception studies are under ordinary conditions, and the method to deal with the adverse weather conditions was ignored. Hence, this paper proposes an all-in-one gated adversarial network (AIO-GAN) to improve the performance of vision-based environment perception algorithms under adverse weather conditions, including in rain, haze, lack of light, etc. Three key technical contributions are made. At first, the deep learning based gated transformer module was proposed to classify the input mixed images to different collections by passing them through different branches. Second, the multi-branch based variational autoencoder-generative adversarial network was proposed to solve the ill-pose problem of the solution. Third, high-level weight sharing encoders was given out to guarantee the stability and the high quality of the training process. In this way, the unified clean-style images can be achieved, even if the mixed multi-modal images are transferred from the source domain of complex weather scenes. Extensive experimental results show that the proposed method has achieved better performance than state-of-the-arts and improved the accuracy of target detection.

Preliminary Study of Tactical-Level Interaction for Highly-Automated Vehicles: Its Application to Touchscreen Interface

M. Kamezaki, U. E. Manawadu, M. Ishikawa and S. Sugano

In automated vehicles, drivers are only required to input high-level control commands. The conventional driver-vehicle interfaces (DVIs) such as steering wheel and pedals may not be utilized in higher levels of automation. A DVI that allows the driver to input tactical-level control commands, i.e., lane change and turning would be potentially required for automated vehicles. This paper proposes tactical-level-interaction (TLI) for controlling highly automated vehicles and the experimental results show the effectiveness of a touchscreen-based DVI prototype.

Predictive Thermal Management for an Electric Vehicle Powertrain

S. Schaut, E. Arnold and O. Sawodny

The design of thermal management strategies for electric vehicle powertrains is an important task, since these strategies influence performance, energy consumption, safety and durability of the powertrain operation. In the present paper, a predictive thermal management strategy for the powertrain cooling system is developed. The aims are to minimize the energy consumption of the cooling system, to increase the efficiency of the electric motors and to operate them in a temperature area of safety and durability. The thermal management strategy is realized by a real-time capable nonlinear model predictive controller, incorporating a dynamical model for the powertrain of the battery electric vehicle under consideration. The usage of this model-based approach ensures a fast adaption of the control strategy to different vehicle architectures. Since predictions of the disturbances acting on the system are uncertain in general, the control strategy is extended by a stochastic model predictive control approach to handle uncertainties in the disturbance prediction. The effectiveness of the resulting strategies is demonstrated using an accurate simulation model. Special attention is given to the possible energy savings, the robustness with respect to uncertainties, as well as the computational effort of the algorithms.

FAIR: Towards Impartial Resource Allocation for Intelligent Vehicles With Automotive Edge Computing

H. Wang, J. Xie and M. Muslam

The paper proposes FAIR, an end-to-end automotive edge networking system, that can provide fast, scalable, and impartial connected services for intelligent vehicles with edge computing. This is the first work that systematically addresses the issue of the asymmetrical resource allocation for uplink and downlink connections in traditional wireless networks. The core of FAIR is symmetrical network resource allocation and service adaptation algorithms. The effectiveness of the proposed FAIR is validated by dataset collected in multiple real-world traffic scenarios and road topology.

Predictive Neural Motion Planner for Autonomous Driving Using Graph Networks

X. Mo and C. Lv

A predictive neural motion planner is proposed for autonomous driving. Several neural motion planning baselines are implemented to investigate the impacts of the historical states of other agents on planning performance. Two multi-agent trajectory predictors of different accuracies are implemented and incorporated into the predictive planner to investigate the relationship between

prediction and planning. Experiments show that the information on other traffic participants' future motions is useful for neural planning.

Driving Behavior Modeling and Characteristic Learning for Human-Like Decision-Making in Highway

C. Xu, W. Zhao, C. Wang, T. Cui and C. Lv

This paper proposes an integrated model and learning combined algorithm to realize human-like driving. It includes the integrated driving behavior modeling to ensure basic safety and the characteristic learning to further imitate human driver's style. The algorithm is validated in both highD dataset and driver simulator. The results show that the safety and efficiency in this process are quite approximate, which has good human-like performance.

II. Testing Intelligence: Accelerating the Verification and Validation of Intelligent Vehicles

The Verification and Validation of intelligent vehicles has been drawing great attention over the last few years.

V&V of intelligent vehicles is critical. It helps reduce the operation risk before IVs are released to public roads. It was first introduced as scenarios engineering [4], [5] decades ago. It has been evolving since then [6], [7]. To conduct reliable and trustworthy V&V for IVs, a variety of testing methods have been developed, including fault injection testing, data-driven testing, knowledge-based testing, etc. These testing methods typically explore critical scenarios/situations with high risks for IVs. However, due to the limitation of datasets and human knowledge, the testing is of no/low intelligence and can only find the critical scenarios/situations that are known or known unknown. In fact, there are still plenty of high-risk cases that are unexplored or "unknown unknowns". This issue holds back the advancement of IVs. Hence, it is urgent to develop procedures for testing intelligence to go beyond the limits of data and knowledge. It is widely believed that, via testing intelligence, the V&V of IVs can be further enhanced and additional unknown high risks can be found.

To develop testing intelligence, it remains a question of how to define and quantify the intelligence of testing. Testing intelligence can be viewed as beyond-human searchers who explore potential risks for intelligent vehicles. In this sense, the intelligence of testing can be quantified by the capacity of risk exploration. Existing research has provided various metrics for this quantification. These metrics include but are not limited to [8]: i) coverage, the capacity of covering high-risk situations as many as possible; ii) evolvability, the capacity of discovering high-risk cases that have never been explored. iii) efficiency, the capacity of saving time and resources to explore critical risks; iv) interpretability: the capacity of providing exploration approaches in a white-box manner. Since existing testing methods in the literature have great room for improvement in terms of these metrics, the current testing intelligence is still in an early stage.

During this early stage of testing intelligence, three research directions are called for attention: testing scenario library generation, testing process automation, and testing toolbox enhancement. Testing scenario library generation leverages datasets/knowledge to generate concrete scenarios for risk exploration[9]. Obviously, if abundant high-risk scenarios, the coverage and evolvability of testing can therefore be significantly improved. Testing process automation organizes all the testing processes in a logically automatic loop [10] and enables accelerated testing through emerging approaches such as artificial intelligence [11] and parallel learning and testing[12]. If such an organization performs well, the extra time caused by humans could be reduced and related resources including labor, funds and assets for testing would be saved. Hence, through testing process automation, higher testing efficiency might be achieved. Testing toolbox enhancement upgrades existing testing tools, e.g., simulation platforms, test benches and field facilities, and creates new tools compatible with the status quo of testing intelligence. The enhanced toolbox facilitates scenario reproduction, testing process monitoring and testing result analysis. These toolbox functions make the complex testing tasks understandable intuitively and easily by test runners. Thus, using the enhanced toolbox, the interpretability of testing can be enhanced as well. The research on these directions is limited and requires more devoted efforts from the academic and industrial communities in the field of testing engineering.

The future development of testing intelligence encounters three main challenges: 1) Establishing a universal framework for testing intelligence. Existing studies of testing engineering are scattered and do not form a consensus on the development route. It is urgent to set up a general framework to guide the research of testing theories, methods and techniques. 2) Covering multiple metrics of testing intelligence. Existing testing methodologies can only perform well in terms of one/two of the metrics mentioned above. New methodologies are needed to cover multiple metrics of testing intelligence. 3) Filling the gaps of datasets that serve testing. Datasets of intelligent vehicles are vital for testing. However, these datasets are scarce and usually of proprietary. An alternative way to acquire datasets is to collect data from high-fidelity simulations. Such data acquisition is challenged by the balance between simulation efficiency and fidelity.

Overall, testing intelligence is a challenging research direction and is expected to attract more contributions.

III. Call for Participation: Decentralized Hybrid Workshops

We at TIV 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 in IVs. 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, any suggestions or proposals for future topics are greatly appreciated.

Looking forward to having you in our DHW or DHS.

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