Scenarios Engineering: Enabling Trustworthy and Effective AI for Autonomous Vehicles

Dear All,

I would like to share with you the following good news:

- The first journal impact factor (IF) of IEEE TIV is 5.009 with a CiteScore = 10.9 in 2022, signifying a promising start for our periodical. By April 2023, our real-time IF stands at 7.03 according to Web of Science, and CiteScore from Elsevier is 11.6. These numbers indicate that IEEE TIV is among the top-tier publications in the related fields.
- In the first quarter of 2023, our periodical received a total of 689 original submissions, the average number of submissions per day rate is 7.66. This indicates a positive trend of growth. I would like to express my heartfelt gratitude to our editorial members for your unwavering commitment and dedicated efforts in moving IEEE TIV into a new phase in serving our professional community.

The current issue comprises 3 letters and 22 regular papers. All letters are the outcome from our decentralized and hybrid workshops (DHW): the first letter results from our DHW on Scenario Engineering (SE), the second from Intelligent Vehicles for Education (IV4E), and the last from Ethics, Responsibility, and Sustainability (ERS).

Our editorial focuses on Scenario Engineering (SE) for Autonomous Vehicles (AVs), and we have already conducted 2 decentralized and hybrid symposia (DHS) and 4 DHWs on this project. After *Scanning the Issue*, we would like to address issues related to Trustworthy and Effective Artificial Intelligence for AVs based on the SE methodology.

I. Scanning the Issue

Heuristics for Multi-Vehicle Routing Problem Considering Human-Robot Interactions

V. S. Chirala, K. Sundar, S. Venkatachalam, J. M. Smereka and S.Kassoumeh

This paper consider a multiobjective, multiple-vehicle routing problem in which teams of manned ground vehicles (MGVs) and AMRs are deployed respectively in a leader-follower framework to execute missions with differing requirements for MGVs and AMRs while considering human-robot interactions (HRI). HRI studies highlight the costs of managing a team of follower AMRs by a leader MGV. This paper aims to compute feasible visit sequences, replenishments, team compositions and number of MGV-AMR teams deployed such that the requirements for MGVs and AMRs for the missions are met and the routing, replenishment, HRI and team deployment costs are at minimum. The problem is first modeled as a a mixed-integer linear program (MILP) that can be solved to optimality by off-the-shelf commercial solvers for small-sized instances.

Railway Virtual Coupling: A Survey of Emerging Control Techniques

Q. Wu, X. Ge, Q.-L. Han and Y. Liu

This paper is concerned with the networked cooperative path following (CPF) problem for multiple autonomous surface vehicles (ASVs) subject to simultaneous cyber and physical attacks. First, to compensate the adverse effects of the physical-attack-induced bias injections, an extended state observer is designed to provide real-time estimates of the unmeasured velocities and unknown nonlinear terms. Next, to identify and handle various cyber attacks, a novel secure data transmission mechanism, featuring a secure transmitter and a secure receiver, is developed for each ASV. Then, a secure CPF control scheme, consisting of a networked cooperative kinematic control law and a networked kinetic control law, is presented. Furthermore, the observer error dynamics and networked CPF error dynamics are derived to account for the simultaneous network-induced delays, packet dropouts, physical attacks, and cyber attacks.

Shared Steering Control With Predictive Risk Field Enabled by Digital Twin

Y. Liang, Z. Yin, L. Nie and Y. Ba

A novel shared controller in the framework of multiobjective MPC is designed to minimize the driving risk while matching driver's commands, so that safe cooperative driving is achieved in a smooth and minimal-intervention manner.

Learning Autonomous Control Policy for Intersection Navigation With Pedestrian Interaction

Z. Zhu and H. Zhao

Navigating through densely populated intersections poses challenges to autonomous driving due to the uncertainty introduced by other traffic participants. A multi-task conditional imitation

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learning framework is proposed to adapt both lateral and longitudinal control tasks for safe and efficient interaction with other agents. A new benchmark called IntersectNav is developed and human demonstrations are provided. Empirical results show that the proposed method achieves a high performance compared to the state-of-the-art.

Cyber-Physical Optimization-Based Fuzzy Control Strategy for Plug-in Hybrid Electric Buses Using Iterative Modified Particle Swarm Optimization

C. Yang, R. Chen, W. Wang, Y. Li, X. Shen and C. Xiang

A cyber-physical optimization-based fuzzy energy management strategy is proposed. To eliminate the conflict between parameter optimization and real-time operation of control strategy, a cyber-physical system framework is formulated. An interval type 2 fuzzy control with optimization parameters is developed using iterative modified particle swarm optimization to improve the fuel economy and battery life. The effectiveness of the proposed method is demonstrated with simulation and hardware in loop test.

Relaxed Actor-Critic With Convergence Guarantees for Continuous-Time Optimal Control of Nonlinear Systems

J. Duan, J. Li, Q. Ge, S. E. Li, M. Bujarbaruah, F. Ma and D. Zhang

A Relaxed Continuous-Time Actor-critic (RCTAC) algorithm is proposed to find the nearly optimal policy for general nonlinear continuous-time systems. It does not require the admissibility of the initialized policy or the input-affine nature of controlled systems for convergence. The convergence and optimality of the algorithm are proven through Lyapunov analysis, and its effectiveness is demonstrated through simulations and real-world path-tracking tasks.

The AD4CHE Dataset and Its Application in Typical Congestion Scenarios of Traffic Jam Pilot Systems

Y. Zhang, C. Wang, R. Yu, L. Wang, W. Quan, Y. Gao and P. Li

The paper presents an open-source aerial dataset focusing on Chinese highway and expressway congestion scenarios. It contains 5.12 hours of driving data with a total driving distance of 6540.7 km. To aid the development of Traffic Jam Pilot systems, overlap cut-in scenarios are defined and parameterized. The driving behavior in extracted overlap cut-in scenarios is analyzed. The dataset and obtained results are valuable for testing Traffic Jam Pilot systems.

Integrated Control of Steering and Braking for Path Tracking Using Multi-Point Linearized MPC

J. Lee and S. B. Choi

In this study, we propose an integrated braking and steering model predictive controller for stable and accurate path tracking. This paper proposes a multipoint linearization method to minimize the linearization error, and a controller with good computational efficiency and accurate consideration of nonlinear vehicle behavior is also introduced. In addition, the proposed model predictive controller (MPC) actively utilizes the road friction limit constraint for each tire force to ensure vehicle stability. Through this, the proposed controller generates optimal braking and steering inputs for situations such as high-speed turns in which braking must be involved.

Efficient and Unbiased Safety Test for Autonomous Driving Systems

Z. Jiang, W. Pan, J. Liu, S. Dang, Z. Yang, H. Li and Y. Pan

A unified and hierarchical test framework for efficient and unbiased safety testing of autonomous driving systems (ADS) is proposed. The test cases are derived from the risk subspace using data preprocessing and Kriging model-based Importance Sampling techniques. With the simulation results skewered back to the risk subspace, the ADS probability of failure can be estimated in an unbiased manner. The experimental results show that the proposed method can accelerate the ADS safety test under challenging but realistic traffic conditions.

Multi-Modal Interaction-Aware Motion Prediction at Unsignalized Intersections

V. Trentin, A. Artu±edo, J. Godoy and J. Villagra

To assure safety while navigating through highly interactive complex scenarios, intention estimation and motion prediction are fundamental. This paper proposes a method to infer the intentions, based on a Dynamic Bayesian Network, and predict the motion of the nearby vehicles, using Markov Chains, at unsignalized intersections. The interaction between vehicles is used to infer the intentions that are fused with the motion predictions computed with a kinematic model to result in a motion grid used by the ego vehicle to navigate through the scene.

Vehicle Control on an Uninstrumented Surface With an Off-the-Shelf Smartwatch

H. Kim, H. Lee, J. Park, L. Paillat and S.-C. Kim

In this study, we propose a user interface, designed for an automotive environment for recognizing input commands. As the use of extra elements to extend the scope of interactions may visually distract users during driving, we focus on using body parts as an interaction space. Specifically, we utilized the lap

as an interaction hyperplane due to its near-flat surface, which provides users interaction analogous to a touchpad.

A Comfort Quantification Method Based on Semi-Supervised Learning for Automated Vehicle at Lane Change Scenarios

W. Zhu, X. Zhang, C. Hu, B. Zhao, S. Peng and H. Yang

Utilizing psychological and physiological reactions of passengers, this article systematically investigates the passenger comfort quantification method for automated vehicle based on passenger heterogeneity, AM-Bi-LSTM, and semi-supervised learning. A comfort quantification dataset is gathered in urban environments, the passenger heterogeneity is evolved into the dataset. The onboard comfort inference results of automated vehicle in urban environments revealed that the developed quantification system is exceptionally effective for passenger comfort degree evaluation of automated vehicle.

Multi-Modal Feature Constraint Based Tightly Coupled Monocular Visual-LiDAR Odometry and Mapping

C. Shu and Y. Luo

A multi-sensor fusion framework for tightly coupled monocular visual-LiDAR odometry and mapping is proposed. The framework fully utilizes the constraints amongLiDAR features and visual features and integrates that in a tightly coupled approach. The evaluation results show that the proposed fusion framework achieves comparable performance compared to the state-of-the-art visual-LiDAR odometry frameworks.

Adaptive Fixed-Time Antilock Control of Levitation System of High-Speed Maglev Train

T. Zhang, D. Shen, S. Jiang and H. Xu

This paper addresses the lock problem in EMS maglev trains, which is critical to operational safety. To prevent physical contact between a vehicle and track and guarantee safety, an adaptive fixed-time antilock levitation controller is proposed considering both track irregularities and external disturbances. The simulation results fully demonstrate the effectiveness and robustness of the proposed control scheme.

CADer: A Deep Reinforcement Learning Approach for Designing the Communication Architecture of System of Systems

M. Lin, T. Chen, B. Ren, H. Chen, M. Zhang and D. Guo

A deep reinforcement learning-based model named 'CADer' is proposed to solve the communication architecture design problem for combat System of Systems(SoS-CAD). The attention mechanism and dynamic embedding mechanism are introduced into CADer with considering the characteristics of the SoS-CAD. Experimental results demonstrate the effectiveness of the proposed model.

Adaptive Correction of Landmark for Visual Homing in Mobile Vehicles

X. Ji, G. Sun, M. J. Er and Z. Wang

This paper presents an optimized visual homing method based on Average Landmark Vector(ALV), termed Adaptive Correction of Landmark (ACoL), which exhibits good homing performance and robustness in both static and dynamic indoor environments. The proposed method focuses on improving a vehicle's homing ability in terms of landmark matching, landmark distribution and homing direction. The experimental results show that the proposed method generalizes well to various complex and challenging indoor scenarios.

Road Shape Classification-Based Matching Between Lane Detection and HD Map for Robust Localization of Autonomous Cars

S. Kim, S. Kim, J. Seok, C. Ryu, D. Hwang and K. Jo

We proposed a road shape classification-based map-matching algorithm to overcome the under-constrained problems, which have no unique solution. The proposed algorithm classifies lane segments into line, arc, and clothoid curves considering their curvature characteristics. For the under-constrained shapes, the geometry-based map-matching algorithm and covariance estimation method are applied to avoid underdetermined results.

Secure Task Offloading for MEC-Aided-UAV System

P. Chen, X. Luo, D. Guo, Y. Sun, J. Xie. Y. Zhao and R. Zhou

This paper investigates a new secure task offloading scheme for MEC-aided-UAV system, including joint optimization of the trajectory and transmit power of the UAV, the transmit power of the AN, the local computation ratio, and the selection of the GBS to Max-Min-ASC. Moreover, it proposes an efficient algorithm based on the BCD method and the SCA technique while proving the algorithm's convergence. Numerical results show that the proposed algorithm superiors the benchmark schemes.

Emergency Collision Avoidance and Mitigation Using Model Predictive Control and Artificial Potential Function

X. Shang and A. Eskandarian

A new artificial potential function inspired by the line charge is proposed and combined with model predictive control to realize collision avoidance and mitigation for autonomous vehicles. The proposed method has the flexibility to fit the shape of different

kinds of obstacles and could achieve pre-assigned part protection by placing an additional point charge.

Optimizing Vehicle Re-Ordering Events in Coordinated Autonomous Intersection Crossings Under CAVs' Location Uncertainty

C. Vitale, P. Kolios and G. Ellinas

This work proposes a novel Intersection Manager (IM) that safely maximizes the intersection capacity even when the present and future CAVs' location is uncertain. To fully exploit the communication links between the IM and the CAVs, several features are included in the proposed framework: (i) periodic re-optimizations of the CAVs' applied controls; (ii) periodic re-ordering of the intersection crossing sequence; and (iii) event-based control and ordering optimizations to achieve the best possible trade-off between complexity and performance.

Improving 3D Vulnerable Road User Detection With Point Augmentation

W. Lu, D. Zhao, C. Premebida, L. Zhang, W. Zhao and D. Tian

This paper proposes Point Augmentation (PA)-RCNN, focusing on small object detection by generating efficient complementary features without trainable parameters. Specifically, 3D points are sampled with the guidance of object proposals and encoded through the 3D grid-based feature aggregation to produce localized 3D voxel properties. Such voxel attributes are fed to the pooling module with the aid of fictional points, which are transformed from sampled points considering geometric symmetry.

Open-World Learning for Traffic Scenarios Categorisation

L. Balasubramanian, J. Wurst, M. Botsch and K. Deng

An open-world learning method is proposed to identify, collect, and cluster unknown traffic scenarios. New clusters are incrementally added to the already existing traffic scenario categories. The open-world learning method is based on a hierarchical architecture that contains novel machine learning approaches like Random Forest Activation Patterns for clustering, class-conditioned generative models for replay, and self-supervised pre-training for feature generation.

II. Enabling Trustworthy and Effective AI for AVs

Scenario-based approaches have been receiving a huge amount of attention in research and engineering of autonomous vehicles (AVs) [1].

Scenarios engineering (SE) [2], [3] is proposed to achieve trustworthy and effective AI for AVs. It was inspired by parallel intelligent [4], [5] (PI), which provides an effective way of making small data into big data and then refining big data into deep intelligence for specific tasks. Furthermore, the mechanism of the PI can inspire designs for theoretically and practically plausible complex systems or artificial intelligence (AI) systems [6]. AI is playing an important role in the development of AVs, allowing them to perform advanced functions, [7], [8] such as autonomous driving [9], visual perception [10], collision avoidance [11], and route planning, etc. However, anybody who has worked with AI knows these systems occasionally make silly mistakes in critical scenarios. For example, a pedestrian suddenly crossing the street or a sudden change in weather conditions can pose a challenge to the vehicle's sensors and decision-making algorithms. AVs may encounter above situations on the road that they have never seen before, and without sufficient training data, they may not know how to respond. Such events may be rare or unexpected and may be challenging to predict or simulate. To ensure the safety of passengers, drivers and other road users, it is necessary to calibrate and validate the overall performance of AI-based AVs under a range of critical scenarios.

At present, feature engineering is a main step in the development of AI models. Feature engineering is the process of selecting and transforming raw data into features that can be used as input to an AI model. It is an important stage in the machine learning pipeline because the quality of the features can significantly impact the performance of the model. The goal of deep learning combined with features engineering is to simplify and speed up the data transformation while improve the accuracy of the AI models. Nevertheless, AI is essentially the black box models created directly from data, resulting that even designers cannot clearly understand how variables are being combined to make predictions.

That is the reason why SE has been presented, hoping to change the field of AI-based AVs [12], [13]. It is defined as an integrated reflection of the scenarios and activities within a certain temporal and spatial range, where all actionable AI are encouraged to complete the design, calibration and verification. SE can provide key elements or quantitatively analyze the critical factors that affect the performance of AI. The notion of trust and effectiveness depend not only on the visibility that a human has into the working of the machine, but also on the controllability of the learning features (data from scenarios) of the model. To be specific, scenarios can be understood in many ways, either as a sequence of activities or as a branching structure of those activities. Besides, a scenario can be concrete or abstract, which means it can be real, virtual, parallel, or various intermediate options. Therefore, we can both fully sample the driving scenarios that may be encountered in practice, and learn to generate challenging scenarios to calibrate and improve the capability of autonomous vehicles [14]. The SE consists of six key dimensions, including Intelligence and Index (I&I), Calibration and Certification (C&C), Verification and Validation (V&V). First, I&I provides goals and metrics to effectively evaluate the performance and function of the AVs. Second, C&C guarantees that the internal parameters of the system under test are at reasonable levels, and a certification would be issued for the third party recognition after calibration [15], [16]. Third, V&V uses a combination of simulation, real testing, and analysis techniques to ensure the safety and reliability of intelligent

vehicles, particularly in critical scenarios. Overall, SE can be used throughout the AVs algorithms life-cycle to clarify the operation processes; to set goals (or index) for both experts and AI [17], [18]; to determine suitable model structures and parameters after system training; to provide a certification is issued by a third-party; to validate user requirements before system specification begins; and to evaluate system design, performance and function.

The use of SE in the AVs community has several benefits. First, it enables the development of AVs that is more reliable and robust. By training the AI system on a wide range of scenarios, developers can address potential weaknesses before the vehicle is deployed on the road. Second, SE can help to ensure that AI-powered vehicles are safe and secure. By testing the system on critical scenarios, developers can identify potential security vulnerabilities and address them before the vehicle is deployed on the road. Finally, SE can help to build trust in AI-based AVs. One of the main concerns about AI-powered vehicles is the lack of transparency in how the system makes decisions. By using SE, developers can ensure that the AI system is transparent and can explain its decisions to the driver and other stakeholders. SE aims at shaping the AI-based AVs to be a form that is more relevant to the underlying scenario that will be learned and tested [19]. This allows AVs to detect and respond to a wide range of scenarios, from straightforward situations like navigating a straight road to more complex scenarios like avoiding collisions with other vehicles and pedestrians.

In summary, the development of AVs is an exciting and rapidly evolving technology that has the potential to transform the way we travel. For assuring safety of AVs, SE focuses on understanding the operational design domain and defining the cases for intelligent vehicles, where it is essential to be able to derive critical scenarios efficiently and effectively. It should be noted that when applying simulation scenarios to real-world, the gap between the appearance and content domains needs to be reduced [20], [21]. Moreover, the quality assurance of existing AI application remains a challenge with increasing demand for safe driving. The formulation of metrics takes at times considerable efforts to realize "6S" goals for intelligent vehicles: safety in the physical world, security in the cyber world, sustainability in the ecological world, sensitivity to individual needs, service for all, and smartness in all. By performing thorough V&V, developers can ensure that the AI in intelligent vehicles is trustworthy and effective. This can increase public confidence in the safety and reliability of these vehicles, leading to wider adoption and greater use. Additionally, the real-road testing [22] and human-in-loop simulation systems [23] can help identify and address any issues that may arise over time, ensuring that the AI remains effective and trustworthy throughout the life of the Avs.

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 ITS and IVs.

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. The following DHWs have been organized so far:

1) Verification and Validation for IVs (V&V4IV)
2) Autonomous Mining (AM)
3) Ethics, Responsibility, and Sustainability (ERS)
4) Intelligent Vehicles for Education (IV4E)
5) 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.

Xuan Li, *Associate Editor*
Department of Mathematics and Theories
Peng Cheng Laboratory
Shenzhen 518055, China
e-mail: lix05@pcl.ac.cn

Fei-Yue Wang, *Editor-in-Chief*
State Key Laboratory for Management
and Control of Complex Systems
Institute of Automation
Chinese Academy of Sciences
Beijing 100190, China
e-mail: feiyue@ieee.org

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