Crowdsensing Intelligence: Advancing Trustworthy, Intelligent, Interactive, and Cooperative Sensing and Computing for Transportation 5.0

Dear All,

I am delighted to share with you the following messages for IEEE TIV: i) On June 20, 2023, the IEEE TIV received its 2000th submission and the Submission Per Day is 9.95; ii) It is expected that over 3650 submissions would be received this year. Thanks to all of you for your tremendous effort and enthusiastic dedication in serving our TIV. This also implies more work for processing and evaluation; therefore we need to speed up our effort to recruit more able and responsible Associate Editors and Reviewers. I need help from you in this hard but important task [1], [2], [3], [4].

Next, I would like to take this opportunity to announce the 2021 George N. Saridis Best Paper Award of the IEEE TIV [3] for recognizing the best regular papers and survey papers published between Jan. 2019 and Dec. 2022 in the IEEE Transactions on Intelligent Vehicles.

The award Ie followed a rigorous process to select the best papers. Firstly, the Top 15 most-cited papers according to Google Scholar, plus any papers solicited or nominated through the open call, are considered as Candidate Papers. Next, the Award Committee is responsible for organizing the review process to select 2–3 papers as the Finalist Papers from the Candidate Papers. Finally, the Award Committee is gathered to discuss and decide the final Best Paper.

The following is the list of final results for the 2021 George N. Saridis Best Transactions Paper Award.

I. The George N. Saridis Best Transactions Paper Award for Outstanding Research

K. Messaoud, I. Yahiaoui, A. Verroust-Blondet and F. Nashashibi, **"Attention Based Vehicle Trajectory Prediction,"** *in IEEE Transactions on Intelligent Vehicles*, vol. 6, no. 1, pp. 175–185, March 2021, doi: 10.1109/TIV.2020.2991952. (Google Scholar Citations: **133**)

M. Koschi and M. Althoff, **"Set-Based Prediction of Traffic Participants Considering Occlusions and Traffic Rules,"** *in IEEE Transactions on Intelligent Vehicles*, vol. 6, no. 2, pp. 249–265, June 2021, doi: 10.1109/TIV.2020.3017385. (Google Scholar Citations: **54**)

Congratulations to all authors!

The current issue comprises 2 letters and 12 regular papers. All letters are the outcome of our decentralized and hybrid workshops (DHW): the first letter results from our DHW on Scenarios Engineering (SE), the second from Intelligent Vehicles for Education (IV4E), and the last from Ethics, Responsibility, and Sustainability (ERS).

Our editorial focuses on CrowdSensing Intelligence for Transportation 5.0, we have already conducted 4 decentralized and hybrid symposia and 6 DHWs on this project. After Scanning the Issue, we would like to address issues related to Crowdsensing Intelligence for Transportation 5.0.

II. Scanning the Issue

Emerging Trends in Intelligent Vehicles: The IEEE TIV Perspective

H. Zhang, J. Guo, G. Luo, L. Li, X. Na, X. Wang, S. Teng, S. Ma and Y. Li

This paper is focused on bibliographic analysis and collaboration pattern analysis of the papers published in the IEEE Transactions on Intelligent Vehicles (TIV) from January 2019 to January 2023. We have identified the authors, institutions, and countries/regions that are the most productive and have the highest impact. It is found that research on intelligent vehicles is dominated by researchers and institutions from China. Researchers from the US are the second largest contributor to the transaction, whilst those from Germany rank the third. It is also found that, Fei-Yue Wang, Mohan Manubhai Trivedi, and J. Christian Gerdes are the three most productive and influential authors at IEEE TIV, and the Institute of Automation, Chinese Academy of Sciences, National University of Defense Technology, and the University of California, are three most productive and influential institutions. In addition, three networks are generated (i.e., the co-authorship, co-keyword, and author-keyword) to mine collaboration patterns among authors and keywords.

Incorporating Driving Knowledge in Deep Learning Based Vehicle Trajectory Prediction: A Survey

Z. Ding and H. Zhao

From the perspective of introducing driving knowledge, this paper systematically investigates the research status of Deep Learning-based Vehicle Trajectory Prediction methods. The

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problem formulation, knowledge incorporation, and the dataset and evaluation of VTP are reviewed and discussed. Finally, the challenges and open questions of existing VTP research are also analyzed, which puts forward an outlook on future research directions.

Multi-Agent Reinforcement Learning for Cooperative Air Transportation Services in City-Wide Autonomous Urban Air Mobility

C. Park, G. Kim, S. Park, S. Jung and J. Kim

This research proposes an innovative algorithm based on multi-agent deep reinforcement learning (MADRL) which is designed for the autonomous management of air transportation services using urban air mobility (UAM). The proposed algorithm utilizes centralized training and distributed execution (CTDE)-based autonomous mobility control across multiple UAMs. Based on real-world vertiport maps and UAM specifications, it has been confirmed that the proposed algorithm surpasses existing solutions in terms of service quality.

Reconfigurable Holographic Surface Aided Collaborative Wireless SLAM Using Federated Learning for Autonomous Driving

H. Zhang, Z. Yang, Y. Tian, H. Zhang, B. Di and L. Song

Simultaneous Localization and Mapping (SLAM) utilizing millimeter-wave (mmWave) radars is widely recognized as an essential component for autonomous driving applications. In this paper, we present a Reconfigurable Holographic Surface (RHS)-aided SLAM system, incorporating federated learning. The hardware cost of autonomous driving systems can be significantly reduced by replacing the expensive phased array antennas, traditionally used in mmWave radars, with the low-cost RHS metasurface antenna. Furthermore, multiple vehicles can collaborate through the federated learning framework, obtaining additional sensed data to enhance SLAM performance. However, the distinctive radiation structure of the RHS and the information exchange within the federated learning framework introduce complexities to the overall SLAM system design. To address these challenges, we propose a multi-vehicle SLAM protocol that regulates RHS-based radar sensing and data processing across multiple vehicles. Additionally, we design algorithms for RHS radiation optimization and federated learning-based localization and mapping. Simulation results demonstrate the efficacy of the proposed approach when compared to existing phased array-based and noncooperative schemes.

Software-Defined Active LiDARs for Autonomous Driving: A Parallel Intelligence-Based Adaptive Model

Y. Liu, B. Sun, Y. Tian, X. Wang, Y. Zhu, R. Huai and Y. Shen

We propose software-defined active LiDARs based on parallel intelligence to enhance autonomous driving. It optimizes sensing resource allocation by adapting to foreground objects and enables real-time interaction between physical and digital LiDARs in HD maps. Through prescriptive control based on scenario heatmaps, LiDAR hardware operation is redefined, resulting in improved data quality and model performance. Our experiments, using CARLA and the DAWN sensing platform, demonstrate the effectiveness of active LiDARs, particularly in perceiving distant objects.

intrApose: Monocular Driver 6 DOF Head Pose Estimation Leveraging Camera Intrinsics

M. Roth and D. Gavrila

A novel method for continuous 6 DOF head pose estimation from camera images is presented. It leverages camera intrinsics that are essential for accurate pose estimation. Further, employing a continuous, differentiable rotation representation simplifies the architecture. The method was validated on a challenging real-world in-vehicle driver observation dataset that offers a broad spectrum of poses and occlusion states from naturalistic driving. Experiments show significant improvements of rotation error compared to the intrinsics-agnostic baseline with a discontinuous rotation representation.

HYDRO-3D: Hybrid Object Detection and Tracking for Cooperative Perception Using 3D LiDAR

Z. Meng, X. Xia, R. Xu, W. Liu and J. Ma

Our proposed approach called HYDRO-3D aims to improve object detection performance by explicitly incorporating historical object tracking information. Specifically, HYDRO-3D combines object detection features from a state-of-the-art object detection algorithm (V2X-ViT) with historical information from the object tracking algorithm to infer objects. Afterward, a novel spatial-temporal 3D neural network performing global and local manipulations of objecttracking historical data is applied to generate the feature map to enhance object detection. The proposed HYDRO-3D method is comprehensively evaluated on the state-of-the-art V2Xset. The qualitative and quantitative experiment results demonstrate that the HYDRO-3D can effectively utilize the object tracking information and achieve robust object detection performance.

A Parallel Emission Regulatory System for Intelligent Transportation: The Generic Framework and Its Case Study on No_x

Y. Sun, Y. Hu, H. Zhang, F.-Y. Wang and H. Chen

Emission related solutions can be achieved in this system, such as thermal management, vehicle technology selection, green route planning, and penetration of electrification. Since accurate estimation and optimization of vehicle Nox emission is still a challenging issue, a case study on Nox is adopted to demonstrate the effectiveness of the parallel system. The proposed modular integrated emission model (MIEM) is the core of the whole system, which integrates vehicle dynamics, powertrain mechanism, engine combustion, and after-treatment systems (ATS) conversion. Two-parameter gear shifting module and transient

temperature module are the main contributions of the MIEM, while the novel ATS module makes it possible to estimate the tailpipe emissions (rather than engine-out emissions). Experiments under steady state, transient-state, and real-wourld driving emissions (RDE) are conducted with the representative test vehicle to obtain universal characteristics, the WLTC dataset, and two different RDE datasets, respectively.

The Unscented Kalman Filter for Nonlinear Parameter Identification of Adaptive Cruise Control Systems

K. Ampountolas

The core functionality of commercially implemented adaptive cruise control (ACC) systems, including their proprietary control logic and parameters, is not publicly available. This work presents an unscented Kalman filter (UKF) for parameter identification of ACC systems that employ a constant time-headway policy. The filter is evaluated using empirical data of space-gap and relative velocity collected from the onboard sensors of two 2019 SUV vehicles. The parameters obtained reveal that the stock ACC system of the considered vehicles is string unstable.

Privacy-Preserving Proxy Re-Encryption With Decentralized Trust Management for MEC-Empowered VANETs

X. Han, D. Tian, J. Zhou, X. Duan, Z. Sheng and V. Leung

Multi-access edge computing (MEC) technology is widely deployed at the edge of Vehicular Ad hoc Networks (VANETs) to enhance their communication and computational capabilities. However, existing security and privacy preservation solutions for MEC applications in VANETs face several challenges, such as the risk of privacy exposure of vehicle authentication, increased overhead due to cryptographic algorithms, as well as resource occupation and malicious attacks on edge servers. In this paper, we propose an aggregated security solution for the confidential, efficient, and trustworthy sharing of data while safeguarding the privacy of vehicle identities.

Adaptive Path-Tracking Control With Passivity-Based Observer by Port-Hamiltonian Model for Autonomous Vehicles

Y. Ma, L. He, T. Song and D. Wang

The paper proposes adaptive path-tracking control with a passivity-based observer based on port-Hamiltonian models for autonomous vehicles. The proposed method can effectively track the desired path while ensuring the estimation accuracy of lateral velocity under parameter uncertainties and actuator saturations. Moreover, the stability analysis of controller and observer are given. Simulations and experiments are performed to demonstrate the effectiveness of the proposed method compared with other methods.

A Unified Framework for Data-Driven Optimal Control of Connected Vehicles in Mixed Traffic

T. Liu, L. Cui, B. Pang and Z. Jiang

This paper presents a unified approach to the learning-based optimal control of connected human-driven and autonomous vehicles for both freeway and ring road environments. The stabilizability results for both cases are established by the Popov-Belevitch-Hautus test and a novel model reduction technique. Complete solutions of data-driven optimal control, with optimality in the sense of operational costs and disturbance attenuation, are provided using adaptive dynamic programming with rigorous theoretical analysis.

III. Crowdsensing Intelligence for Transportation 5.0

The rapid development of intelligence and connection technology has facilitated the widespread use of mobile devices over the past two decades, promoting the generation of vast amounts of real-time data not only in physical space but also in cyber and social spaces [5]. This phenomenon is equally applicable to various complex systems, including transportation systems. Apart from the traditional way via infrastructure-supported sensor networks, a novel concept of "social sensors" has been proposed to collect data from a humanized perspective through social networks [6]. The social Big Data or so-called social signals are driving the transition of traditional transportation systems towards Transportation 5.0, i.e., the society-centered intelligent transportation system (ITS) [7], [8], [9], [10], [11], [12]. In response to this transition, a suite of intelligent sensing schemes is required to effectively capture the dynamic characteristics of Transportation 5.0 across cyber, physical, and social spaces.

Crowdsensing, as an emerging sensing paradigm, leverages the collective intelligence of humans and organizations to gather data and plays an increasingly crucial role in addressing urban-scale monitoring needs [13]. Experiencing rapid development over the past decade, crowdsensing has attained a high level of algorithmic intelligence with various accomplishments on user recruitment, task assignment, incentive design, and data aggregation. However, due to the expansion and the increased complexity of sensing campaigns, traditional crowdsensing faces several intractable challenges, such as inadequate participation of biological humans, limited spatial-temporal coverage, ineffective incentive mechanisms, as well as privacy and security concerns. Additionally, it also exhibits the characteristics of weak interaction, poor cooperation, and low dependability. Hence, the participation confidence of individuals and the proliferation of crowdsensing applications are significantly impacted. In this context, a new generation of crowdsensing is required to organize and schedule heterogeneous sensing resources from different spaces for enabling trustworthy, intelligent, interactive, and cooperative sensing and computing for Transportation 5.0. This sensing paradigm, which we define as Crowdsensing Intelligence (CSI), is supported by technologies such as blockchain, the Internet of Things, mobile Internet, artificial intelligence, and artificial systems. Through the deep integration of three kinds of participants [14] (human-centered swarm intelligence), it leverages the differences in their sensing abilities, the complementarity of computing resources, and

cross-space collaboration to build a decentralized, self-organizing, self-learning, and continuously evolving intelligent sensing and computing space. In this space, individual skills and collective cognitive ability can be enhanced to facilitate the guidance and control of the actual system [15].

By organizing Distributed/Decentralized Hybrid Workshops on Crowdsensing Intelligence (DHW-CSI), we aim to explore the fresh new sensing paradigm and gain preliminary insights into its framework, participants, implementation methods, and development stages. The initial exploration of CSI for Transportation 5.0 can be traced back to the Cross-Space Collaborative Enhanced Crowdsensing based on Parallel Transportation Systems (CCEC-PTS) [16]. This rudiment framework integrates heterogeneous sensing resources in social transportation and collects associated data from different spaces. Specifically, Parallel Transportation Systems (PTS) are employed to optimize crowdsensing plans while the collected data can further promote the optimization of PTS. As a result, this framework is capable of providing better smart services for ITS. The formal exploration of CSI was launched by Professor Wang Fei-Yue and Chen Bin in the ongoing DHW-CSI [17], [18]. The previous report on our initial DHW-CSI discussion focused on the fundamental principles and high-level procedures for organizing and operating CSI [17]. With the help of smart contracts, a decentralized autonomous organization and operation form of crowdsensing is achieved through encoding various related rules on a blockchain. This form effectively addresses challenges related to location privacy preservation, misbehaving entities, data quality control, incentive design, and other pertinent issues. The discussion of the second DHW-CSI was related to participants, methods, and stages [18]. To effectively organize heterogeneous sensing resources, the participants of CSI are categorized into three kinds: biological, digital, and robotic participants. To enhance CSI and guide these participants, three methods are summarized: foundation models, scenarios engineering, and human-oriented operating systems. Furthermore, the CSI promoted by these three methods will undergo three stages: from algorithmic intelligence to linguistic intelligence and finally to imaginative intelligence. The trend is witnessed in other domains as well [19], [20].

The CSI is now transitioning from algorithmic intelligence to linguistic intelligence, with the prosperity of Large Language Models (LLMs), such as ChatGPT [21], [22], [23], [24]. Natural language can serve as a communication channel among various entities in crowdsensing, and we believe that a fresh 'conversational crowdsensing' mode represents an ideal form of linguistic intelligence for CSI. Three levels of conversation are included in conversational crowdsensing. 1) Inter-human conversations are the most natural and common form of conversation. For example, biological participants exchange information through conversations to achieve effective collaboration. 2) Human-AI conversations enable better comprehension of requests, clearer instructions for tasks, and increased satisfaction of users. 3) Inter-AI conversations have shown the potential of creating knowledge (e.g., emergent ability). A large number of AI applications and models are employed by digital and robotic participants, endowing them with unique and powerful functions. These AI can accomplish more complex tasks through efficient collaboration facilitated by inter-AI conversations. In fact, several concrete applications have harnessed LLMs to establish connections among various AI models, enabling individuals to solve complex tasks across different domains and modalities [25], [26]. Though promising, we should also note the challenges and caveats of conversational crowdsensing. For instance, fraud and misguidance brought about by the complex conversational relationships and the potential threat of strong AI emerged in inter-AI conversations.

IV. 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)
6) Vehicle 5.0 (V5)
7) CrowdSensing Intelligence (CSI)
8) Scenarios Engineering for Smart Mobility (SE4SM)

Any suggestions or proposals for future topics of DHW/DHS are greatly appreciated. Looking forward to having you in IEEE TIV DHW/DHS.

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