Guest Editorial: Intelligent Autonomous Transportation System With 6G–Series—Part V

WE ARE delighted to introduce the fifth part of the Special Issue on intelligent autonomous transportation systems with 6G, which aims to provide the scientific community with a comprehensive overview of innovative technologies, advanced architectures, and potential challenges for the 6G-supported intelligent autonomous transport systems. Forty-two papers were selected for publication in this issue. All the papers were rigorously evaluated according to the standard reviewing process of IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS. The evaluation process considered originality, technical quality, presentational quality, and overall contribution. We will introduce these articles and highlight their main contributions in the following.

In [A1], Mekala et al. designed and developed an intelligent multi-objective tracking system with a novel measurement model, called the box data association inflate model, to assess each target's object state and trajectory without noise by using the Bayesian approach. The box object filter method filters ambiguous detection responses during data association. The theoretical proof of the box object filter is derived based on binomial expansion.

In [A2], Yang et al. propose a novel algorithm, named PAOFIT, where a projection transformation-aided CSI curve fitting compression algorithm is first proposed to decrease data distortions by improving the orthogonality of signal subspace and noise subspace, and an adaptive weighted average fitting order judgment algorithm is proposed to calculate the fitting order needed in the curve fitting process. Then, the localization parameter and time of flight (ToF) are estimated by CSI reconstruction and parameter estimation. Finally, the location of the target is obtained by substituting these parameters into time difference of arrival (TDoA) wireless localization technology.

In [A3], Zhou et al. propose a computation offloading method with demand prediction and reinforcement learning, named CODR. First, a prediction method based on spatial–temporal graph neural network (STGNN) is proposed. According to the predicted demand, a caching decision method based on the simplex algorithm is designed. Then, a computation offloading method based on twin delayed deterministic policy gradient (TD3) is proposed to obtain the optimal offloading scheme. Finally, the effectiveness and superiority of CODR in reducing delay are demonstrated through a large number of simulation experiments.

In [A4], Sun et al. introduce the L1 norm constraint on the basis of linear time–frequency analysis, and the time–frequency analysis method is implemented from the perspective of inversion, so as to reduce the influence of the multi-solution of the method and improve the method's resolution and focusing. In this paper, two numerical simulation data and one real seismic data of road detection are employed to test the proposed new method.

In [A5], Sun et al. propose a 1-D multi-scale dilated convolution neural network time series classifier (MSDCNN). MSDCNN combines multi-scale CNN and dilated CNN. It can extract multi-scale characteristics from time series and reduce the complexity of the classifier. Furthermore, they propose a pre-training strategy, called meta-transfer metric learning using scale function (MLS). MLS allows the classifier to gain experience from different tasks with various numbers of classes.

In [A6], Shan et al. propose a novel approach for real-time traffic volume prediction on urban links that incorporates vehicle travel trajectories extracted from recorded license plate recognition data using radio frequency identification. A recurrent neural network is used to identify route patterns and predict future routes, and link traffic volume is estimated by aggregating all predicted vehicle trajectories that pass through each base station.

In [A7], Lu et al. introduce a deep-learning image estimation model based on a joint attention mechanism. The network framework uses a deep estimation network Yolov5 and a location-based VANET information fast transmission strategy to work together. This paper also proposes a solution based on the strategy of one-way transmission of shared information and dynamic valuation of a cluster distance threshold with vehicle density.

In [A8], Su et al. propose a novel collaborative motion planning method for multiple autonomous vehicles, leveraging an improved ant colony algorithm. They generate independent subpopulations for each vehicle, establish a multi-objective optimization function to optimize spatial collaboration and trajectory costs, and adaptively adjust the evaporation coefficient to enhance global search ability and convergence speed.

In [A9], Yu et al. propose a semantic-oriented feature coupling transformer (SOFCT) for vehicle re-identification. They introduce a knowledge-based transformer to embed images with discriminative attributes, perform feature extractions

Digital Object Identifier 10.1109/TITS.2024.3369268

for different semantics using the semantic feature extraction (SFE) transformer, and weight patch features via semantics-patches coupling in the patch feature weighting (PFW) transformer, enabling subsequent encoders to extract information effectively.

In [A10], Li et al. study the cooperative strategies between ego vehicle and surrounding vehicles with the naturalistic experiment data and then design an autonomous vehicle control method based on the distributed model predictive control (MPC) in order to consider the interaction relationship of ego vehicles and surrounding vehicles. In [A11], Ma et al. conducted a comprehensive literature review and proposed a novel machine vision architecture that can analyze traffic data in real time in the V2X scenario within ICS. Furthermore, based on the end-to-end latency assessment of the system, a plan is outlined to optimize the latency as per the requirements of the machine vision application. In [A12], Sun et al. propose a tamper-resistant broadcasting (TRBS) scheme for secure communication, which handles the inefficiencies and insecurity of existing identity-based broadcast signcryption solutions. Not only can TRBS protect communication data from being illegally accessed, forged, or tampered with by malicious vehicles, but it can also enable efficient and flexible secure information dissemination between autonomous vehicles.

In [A13], Li et al. propose an RGBD-SLAM method based on object detection using a two-stream YOLOv4-MobileNetv3 convolutional neural network. By combining RGBD SLAM and object detection algorithms, they develop a model capable of quickly generating global sparse maps and dense maps of targets. The integration of a two-stream network enables the extraction of 2-D target information, which, when combined with camera poses from SLAM key frame detection, yields dense 3-D point clouds and object center positions.

In [A14], Lu et al. propose a passenger car sales forecast model based on a convolutional neural network and attention mechanism (PCSFCA). Their innovation lies in utilizing the attention mechanism to assess feature importance, allowing the model to prioritize significant features while disregarding less relevant ones. In addition, they employ convolutional neural networks to extract higher order information from features, enhancing the model's ability to capture complex data distributions. Furthermore, they utilize a 5G network to establish a cloud platform for real-time collection of passenger car sales records, enabling the model to learn in real-time, with experimental results demonstrating the effectiveness of the PCSFCA model compared with benchmark models.

In [A15], Zhang et al. propose a generative adversarial network (GAN)-based ensemble model (GANEM) for predicting the demand for shared bikes in 5G networks to solve the above problem. With the support of 5G networks, real-time transmission and storage of traffic data of shared bikes have become a reality. They then use these data to train the GANEM model to have better generalization performance. The GANEM model first uses GAN to learn the data features of existing shared bike demand to generate new training samples.

In [A16], Jia et al. investigate secure multi-antenna transmission in an AmBC-based intelligent transportation system (ITS) coexisting with a passive eavesdropper with jamming. They propose a cooperative jammer to disrupt the eavesdropper while preserving the legitimate receiver's reception, deriving approximate closed-form expressions of secrecy outage probability (SOP) using the Gauss–Chebyshev quadrature. Furthermore, they analyze the asymptotic behavior of SOP at high signal-to-noise ratio (SNR) and when the number of transmit antennas tends to infinity to provide insights into system design.

In [A17], Zhang et al. propose a novel metro passenger flow forecasting model, TMFO-AGGRU, based on parameter estimation optimization for a graph convolutional gated recurrent neural network (GC-GRU). They introduce graph convolution operations to replace linear operations in gated recurrent neural networks and utilize dynamic characteristic matrices obtained from feature learning to construct an attention mechanism module.

In [A18], Yan et al. study the impact of road bridge blockage effects on mmWave vehicle-to-infrastructure (V2I) links and propose an empirical model to accurately characterize the bridge blockage effect. They conduct channel measurements on typical urban roads using a self-developed mmWave channel sounder and introduce the single road bridge (SRB) model, which addresses deficiencies in existing propagation prediction models by revealing the additional propagation loss caused by road bridges.

In [A19], Sun et al. propose a camouflaged object detection method aimed at identifying pedestrians or vehicles against highly similar backgrounds. They introduce a guide-learning-based multi-scale detection network (GLNet) designed to discern weak semantic distinctions between objects and backgrounds, providing accurate segmentation maps to autonomous driving systems.

In [A20], Wang et al. measure, characterize, and model the propagation channel for mmWave automotive radar with typical configurations in scenarios. Based on the channel measurements in urban street and expressway environments, ray-tracing (RT) technology is verified for modeling important objects regarding radar cross-section and echo power. A hybrid channel model is proposed by integrating RT with the stochastic modeling of targets and surrounding environments, which significantly improves simulation efficiency and provides more flexibility for virtual tests in various complex environments.

In [A21], Zhang et al. design a hierarchical velocity optimization based on the hybrid MPC technique (HVO-HMPC) to reduce fuel consumption and pollution emissions. They construct a distance-domain velocity optimization problem and develop a hybrid MPC scheme combining multiple shooting and MPC techniques to calculate optimal velocity profiles, which are used as reference velocities in a low-level controller.

In [A22], Zhao et al. propose a sanitizable access control system with policy protection (SASP) for VSNs. SASP allows a sanitizer to test and sanitize encrypted data, safeguarding against malicious data publishers, and ensuring that plaintext can only be accessed with a valid key. In addition, SASP separates access policies into attribute names and values, concealing private information in ciphertext to preserve data

users' privacy, with rigorous security analysis and performance evaluations confirming its practicality for VSNs.

In [A23], Kong et al. propose a deep encoder–decoder prediction framework based on variational Bayesian inference. A Bayesian neural network is designed by combining variational inference with gated recurrent units (GRUs) which is used as the deep neural network unit of the encoder–decoder framework to mine the intrinsic dynamics of traffic flow. Then, the variational inference is introduced into the multi-head attention mechanism to avoid noise-induced deterioration of prediction accuracy.

In [A24], Liu et al. propose a digital twin (DT) method and develop a related machine learning-based energy-efficient approach. The channel model examined in this paper takes into account incident waves reflected by moving objects and the impacts of radio signals between various vehicles. Three-dimensional ray tracing is used to model the millimeter-wave channel in the IoV to reflect radio frequency (RF)-domain digital twin matching.

In [A25], Liu et al. present a multi-objective optimization model that integrates the scheduling of three types of equipment—railway cranes, yard cranes, and internal trucks—in a multimodal container terminal. The model handles four container flows (import/export rail and highway) within a shared storage yard, incorporating real-world constraints like train time windows and container dependencies. To solve this complex problem, an adaptive large neighborhood search algorithm coupled with discrete-event simulation was designed.

In [A26], Nguyen et al. introduce a distributed optimization approach for reducing latency in the IoT network supported by satellites and cache-assisted UAVs. The optimization problem is divided into clustering users, caching in UAVs, and power allocation, with methods including a non-cooperative game, genetic algorithm, and quick estimation technique.

In [A27], Jia et al. propose the traffic salient object detection using a feature deep interaction and guidance fusion network (TFGNet). The proposed method detects the complete objects that attract human attention in natural traffic scenes, rather than a certain point without object semantic information, which can provide assistance for target recognition tasks in the domain of intelligent driving. In [A28], Gokasar et al. contribute by introducing SWSCAV, a novel real-time traffic management method utilizing shockwave-speed information and a limited number of connected autonomous vehicles (CAVs) during traffic incidents.

In [A29], Jiang et al. propose SHIP, a State-aware Hybrid Incentive Program for FHV-enabled VCS systems. The proposal categorizes FHVs' operating states and provides a hybrid incentive scheme that incorporates both opportunistic and participatory approaches. They also introduce coverage diversity to reflect the distribution of FHVs and sensing tasks. In [A30], Lin et al. propose an effective Q-learning-based VDTN multi-copy routing algorithm by using node encounter rate to describe the activity and density of nodes. The Q-learning reward factor is determined by the node encounter rate so that the distribution of message copies is controlled and the too high local density of copies can be alleviated. In [A31], Wang et al. propose an algorithm that enhances tracking accuracy by incorporating target information from preceding and subsequent frames in the video. To tackle the issue of drift during target occlusion, the algorithm establishes a feature dictionary by extracting relevant information such as pedestrian contours, key points, and geometric features. Moreover, to address the issue of target drift, this algorithm employs a twin network and a model update mechanism to process the filtered target information.

In [A32], Wang et al. propose a framework for a vehicle stability monitoring system in the automotive field, leveraging digital twin technology. This framework comprises a virtual vehicle model system, a vehicle twin data platform, and a comprehensive monitoring system. In addition, they designed a PSOLSTM algorithm for constructing a side slip angle state estimator model, validated for accuracy and real-time performance through both simulation and real vehicle testing platforms.

In [A33], Ding et al. explore an intelligent identification method for autonomous vehicle trajectories using a friction nano-generator. By harnessing energy from tire-ground friction, this method perceives vehicle motion states, establishes an intelligent identification model, and utilizes machine learning for trajectory prediction and control.

In [A34], Wei et al. propose a design for a multi-sensor environment perception and adaptive cruise control (ACC) system based on the Kalman filter algorithm. The system utilizes multiple sensors to collect data and employs the Kalman filter algorithm to process the data, enabling obstacle detection and tracking. This provides a new solution for environmental perception in intelligent vehicles. Meanwhile, combined with ACC technology, the vehicle speed is adjusted to achieve a safe and efficient autonomous driving experience.

In [A35], Zhang and Pan propose the multi-agent reinforcement learning hierarchical optimal scheduling algorithm (MARLHOSA) to address hierarchical scheduling issues in logistics transport. They model the problem as an infinite Markov decision process, employing constraints to mimic real-world operating conditions and utilize a multi-agent reinforcement learning algorithm with a clipping mechanism to enhance the optimization process. Furthermore, a distributed training architecture is devised to accelerate data collection and training while maintaining quality, demonstrating comparable economic performance to numerical optimization methods through simulation results.

In [A36], Huang et al. propose a semantic loopback detection method for autonomous driving, leveraging instance segmentation and visual SLAM. By integrating image segmentation and visual SLAM, a semantic SLAM system is constructed, with a data association method that combines semantic and geometric information to enhance loopback detection accuracy. The experimental results on the TUM public dataset demonstrate superior loopback detection accuracy compared to traditional bag-of-words methods, indicating the effectiveness of the proposed algorithm in improving SLAM system accuracy.

In [A37], Su et al. propose a distributed cyber-physical-social system (CPSS) architecture for multi-operator ac/dc hybrid distribution systems (HDS) by leveraging

cloud-edge-device cooperation. Their model distinguishes various electric vehicles (EVs) to illustrate cyber, physical, and social system interactions, employing a non-ideal communication alternating direction method of multipliers to mitigate transmission delays and noise.

In [A38], Dai et al. present a new nuclear norm-based tensor completion method, which considers the prior rank information and retains large singular values to approximate the rank of the matrix better. First, to achieve optimized rank parameters, a similar block matrix method is proposed, which takes advantage of the nonlocal similarity to the separation of data and noise. Moreover, an optimal rank estimation algorithm is proposed, which can automatically achieve the truncated threshold parameter through the iterative optimization algorithm.

In [A39], Zhou et al. propose an optimization strategy for commercial vehicle automatic emergency braking (AEB) systems, focusing on mitigating unsafe control behavior to enhance safety and reliability. They derive communication delay laws from real vehicle tests to adjust system parameters and formulate an AEB strategy for intersections, optimizing it based on an analysis of unsafe control behavior.

In [A40], Zhao et al. propose a flexible cross-domain data access control (FC-DAC) system. The method FC-DAC system ensures confidentiality, authenticity, and non-repudiation of transmitted information while enabling high-efficiency ciphertext sharing between various platoons. In addition, the FC-DAC solution allows vehicles with valid authorizations to access signcrypted information quickly and efficiently, even if they belong to different platoons.

In [A41], Zhang et al. propose a new high-precision obstacle detection strategy for MELs (MEL-YOLO) utilizing VEC and C-V2X technologies. They enhance feature extraction capabilities through a convolutional attention mechanism integrated into the neck layer and incorporate a small object-oriented prediction layer in the head for multi-scale feature prediction. In addition, a more efficient loss function is introduced to address the gradient explosion problem, and K-means++ optimization is utilized to derive anchor boxes matchable with the dataset, leading to a compressed MEL-YOLO model deployed on edge devices in a 6G/B5G-based V2X environment.

In [A42], Shao et al. propose an aircraft skin damage detection and evaluation framework by combining gray level co-occurrence matrix (GLCM) and cloud model. In the experimental stage, the UAV picks up the damaged image of the aircraft, and the texture feature data is output by using the GLCM algorithm. The introduction of the cloud model evaluation system makes the skin damage type be quickly judged. The results show that the proposed method has good recognition ability for aircraft skin damage, and the identification accuracy of the verification image set reaches 85%.

We would like to express our sincere thanks to all the authors for submitting their papers and to the reviewers for their valuable comments and suggestions that significantly enhanced the quality of these articles. We are also grateful to Editor-in-Chief, Prof. Azim Eskandarian, for the tremendous support throughout this Special issue's review and publication process and, of course, all the editorial staff. We hope this special issue will serve as a valuable reference for researchers, scientists, engineers, and academics in intelligent autonomous transportation systems.

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APPENDIX: RELATED ARTICLES

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