Guest Editorial Introduction to the Special Issue on Context Prediction of Autonomous Vehicles

THE integration of advanced sensing, signal processing, deep learning, and edge computing into vehicles is enabling intelligent automated vehicles that can navigate autonomously in various environments. There are several exciting developments in new technologies that may contribute to the improvement of the robustness of autonomous vehicles and thus making them safer on the road. However, the development of suitable context prediction methodologies in order to provide proactive behavior for intelligent transportations remains a challenge. The reason is that future context information, hidden in the raw context traces left by users in the real world, is not immediately accessible to applications. Therefore, sophisticated context prediction approaches are required that could discover and mine patterns (e.g., of a driver's behavior) from observed context history. The major challenge of a context prediction approach is in the prediction accuracy and prediction expressiveness. Neural networks along with deep-learning methods have shown noticeably better performance in comparison with previous methods regarding the accuracy of the outcomes. However, deep learning also issues more complexity and interpretability problems and, hence, arises serious challenges regarding the verifiability of these approaches. This Special Issue aims to provide the scientific community with a comprehensive overview of innovative technologies, advanced architectures, and potential challenges for context prediction of autonomous vehicles.

We received a very good response to our open call for papers of the Special Issue. All the articles were rigorously evaluated according to the normal reviewing process of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS. The evaluation process took into consideration factors pertaining to originality, technical quality, presentational quality, and overall contribution. In all, 29 articles were accepted for publication. In the following, we will introduce these articles and highlight their main contributions.

In [A1], Li *et al.* propose an improved 3-D object detection method based on a two-stage detector called the Improved Point-Voxel Region Convolutional Neural Network (IPV-RCNN). They propose a method that contains online training for data augmentation, upsampling convolution, and k-means clustering for the bounding box to achieve 3-D detection tasks from raw point clouds.

In [A2], Munir *et al.* focus on designing a deep learning-based framework, called LDNet, to explore the novel application of lane marking detection under challenging illumination conditions using an event camera. The proposed framework consists of a convolutional encoder followed by an attention-guided decoder. The spatial resolution of the encoded features is retained by a dense Atrous Spatial Pyramid Pooling (ASPP) block. The additive attention mechanism in the decoder improves performance for high-dimensional input encoded features that improve lane localization and relieve the postprocessing computation.

In [A3], Yang *et al.* propose multiagent reinforcement learning for traffic signals (MARL4TS) to support the control and deployment of traffic signals. First, the information on traffic flows and multiple intersections is formalized as input environments for performing reinforcement learning. Second, the authors design a new reward function to continuously select the most appropriate strategy as control during multiagent learning to track actions for traffic signals.

In [A4], Belhadi *et al.* attempt to solve the deficiency of the existing literature in outlier detection thus a novel hybrid framework to identify group anomaly detection from sequence data is proposed in this article. It proposes two approaches for efficiently solving this problem: 1) a hybrid data mining-based algorithm that consists of three main phases: first, the clustering algorithm is applied to derive the micro-clusters. Second, the kNN algorithm is applied to each micro-cluster to calculate the candidates of the group's outliers. Third, a pattern mining framework gets applied to the candidates of the group's outliers as a pruning strategy, to generate the groups of outliers, and 2) a GPU-based approach is presented, which benefits from the massively GPU computing to boost the runtime of the hybrid data mining-based algorithm.

In [A5], Adil *et al.* present three byte-based media access control (MAC) protocol to resolve the mutual authentication problems in an Autonomous Internet of Vehicles (AIoV) network. The network architecture is divided into two chains, i.e., the local and public chains; in the local chains, the authentication and communication process is controlled by cluster heads (CH), while in the public chains, it is controlled by the base stations (BS). The proposed paradigm aims to overcome the vehicle-to-vehicle (V2V) authentication problem in an AIoV network.

In [A6], Zhang *et al.* propose the quantified edge server placement strategy (QESP) in a framework for the IoV system in edge-cloud computing, aiming at improving the coverage

Digital Object Identifier 10.1109/TITS.2022.3185390

rate, the workload balance, and reducing the average waiting time of services. The system model and the problem formulation have been expounded and defined by reasonable argument and derived from strict formulas. Binary encoding and quantum encoding are fully leveraged to model the ES locations. Then, the Niched Pareto Genetic Algorithm II (NPGA-II) and the quantum rotation gate are adopted to obtain the appropriate solutions for the ES placement problem.

In [A7], Li *et al.* propose a source-noise-assisted AmBC transmission scheme in the V2P system, in which the noise is created by the ambient radio frequency (RF) source to improve the PLS performance. The closed-form expressions for the outage probability of the legitimate user and the intercept probability of the eavesdropper are derived. Finally, the diversity gain performance of the system is studied by analyzing the asymptotic behaviors.

In [A8], Cheng *et al.* design a preserving-privacy protocol of vehicle feedback (PPVF) for cloud-assisted vehicular ad hoc network (VANET) to improve the strong security and privacy of vehicle feedback. They apply holomorphic encryption technology allowing RSU to perform mathematical operations on the encrypted data. Thus, each vehicle encrypts individual feedback using Paillier encryption and puts forward it to RSU. Then, RSU aggregates multiple encrypted feedback into one aggregated ciphertext and sends it to the cloud service providers (CSP). Finally, CSP can obtain the sum of the vehicles in each segment of the feedback list without seeing a single vehicle's feedback.

In [A9], Rezaee *et al.* propose a novel and efficient method for identifying social distance. Using stand-alone UAV videos, the method combines human tracking and deep network diagnostics based on population social distance learning. The ShuffleNet learning structure is integrated into the deep architecture, with light and fast changes. Furthermore, the Kalman filter and modified ShuffleNet are used to determine the individual positions and calculate the social distances. In addition, the proposed method can be used in real-time, and its accuracy and sensitivity are satisfactory when identifying social distances.

In [A10], Zhu *et al.* present an NSGA-II-based algorithm for the task scheduling problem in the UAV-enabled mobile edge-computing (MEC) system. The objectives are minimizing the cost and the completion time. Major components of NSGA-II are delicately designed including the feasible solution generation method (FSGM) and genetic operations of crossover, mutation and selection. Three strategies are introduced in FSGM. A simulated annealing local search is integrated into the crossover operation, and meanwhile, two novel mutation methods are proposed.

In [A11], Ding *et al.* present a GAN model for enhancing visually degraded images. With enhanced qualities, these images could provide more information. Subsequently, it may be beneficial for context prediction in autonomous vehicles. The experimental results justified the effectiveness of the proposed method.

In [A12], Cao *et al.* investigate a novel BERT-based deep spatial-temporal network for highly efficient and fine-grained taxi demand prediction. The dynamic temporal periodicity and functional similarity are analyzed and introduced for modeling the spatiotemporal patterns.

In [A13], Schöller *et al.* propose a buoy light pattern classification system to increase situational awareness on marine vessels during the night. The method uses recurrent neural networks together with various stopping criteria that enable the method to run on video streams during image acquisition. Using onboard videos from a marine vessel, the proposed method shows to be able to correctly classify the buoy light patterns present in all evaluated examples.

In [A14], Zhao *et al.* propose a social computing-inspired predictive routing scheme (SPIDER) for SDVNs that has a comprehensive consideration for solving the timeliness and reliability problem of dynamic vehicular networks. As for the link lifetime grounded on the vehicular historical data, the authors introduce the context feature mining and one-shot prediction method to predict vehicle movements with considering energy saving. They also involve social computing techniques to find the relay nodes with good data spreading abilities.

In [A15], Zhang *et al.* present a new benchmark for dense panoramic semantic segmentation (DensePASS), which has pixel-level annotations with 19 classes in accordance with pinhole camera datasets of driving scenes and enables model evaluation. A P2PDA framework with various DA modules is proposed to transfer models from the pinhole to the panoramic image domain. The framework includes attention-augmented adversarial adaptation, attention-regulated self-learning adaptation, and uncertainty-aware distillation. The different DA modules can be flexibly combined with each other to enhance the model transfer.

In [A16], Li *et al.* propose a secure dynamic silent mix zone pseudonym changing scheme (TLAS) based on the real-time traffic context prediction for urban regions, focusing on efficiently replacing pseudonyms with the premise of ensuring driving safety. It naturally takes the area in front of the red traffic light as a silent mix zone, which avoids the driving security issue caused by signal silence. Besides, the area length is dynamically configured according to the traffic context predicted in the last green light cycle, so the anonymous effect can be improved.

In [A17], Xu *et al.* present a general and extensible framework, DeepSuite, to mitigate the manual effort of generating test oracles for deep learning-based autonomous vehicles. The intuition behind this is that not all test inputs are equally worth labelling. With a limited testing budget, it is desirable to label a test suite with high diversity and a reasonable size. DeepSuite employs a three-phase optimization method to iteratively select representative but non-redundant test suites. Such conflicting profit/cost objectives are attained through a genetic algorithm with a well-defined multi-objective fitness function.

In [A18], Duan *et al.* propose a new state representation method, called encoding sum and concatenation (ESC), to describe the environment observation for decision-making in autonomous driving. Unlike existing state representation methods, ESC is applicable to the situation where the number of surrounding vehicles is variable and eliminates the need for manually pre-designed sorting rules, leading to higher representation ability and generality. The proposed ESC method introduces a feature neural network (NN) to encode the real-valued feature of each surrounding vehicle into an encoding vector, and then adds these vectors up to obtain the representation vector of the set of surrounding vehicles. Then, a fixed-dimensional and permutation-invariance state representation can be obtained by concatenating the set representation with other variables.

In [A19], Zhang *et al.* propose a novel multi-level UDA model named Confidence-and-Refinement Adaptation Model (CRAM), which contains a confidence-aware entropy alignment (CEA) module and a style feature alignment (SFA) module. Through CEA, the adaptation is done locally via adversarial learning in the output space, making the segmentation model pay attention to the high-confident predictions. Furthermore, to enhance the model transfer in the shallow feature space, the SFA module is applied to minimize the appearance gap across domains.

In [A20], Wang *et al.* propose a practical comprehensive real-time defense technique CSG to enhance the robustness of traffic sign classifiers for autonomous vehicles in the adversarial context. CSG is constructed by combining Compressive Sensing with Generative neural networks (CSG) and training in a classifier-aware way.

In [A21], Mo *et al.* propose a three-channel trajectory prediction framework to simultaneously predict future trajectories of multiple agents of different types for urban driving. The interactions between different agents are represented by a directed edge-featured heterogeneous graph and a novel Heterogeneous Edge-enhanced graph ATtention network (HEAT) is proposed alongside to handle the heterogeneity of traffic participants.

In [A22], Zou *et al.* present a novel multi-task Y-shaped graph neural network to explore 3-D point clouds, referred to as MTYGNN. By extending the conventional U-Net, MTYGNN contains two main branches to simultaneously perform classification and segmentation tasks in point clouds. Meanwhile, the classification prediction is fused together with the semantic features as the scene context to make the segmentation task more accurate. Furthermore, they consider the homoscedastic uncertainty of each task to calculate the weights of multiple loss functions to ensure that tasks do not negatively interfere with each other.

In [A23], Ayoub *et al.* explore the explainable AI to predict takeover time in conditionally automated driving using a dataset from a meta-analysis study. They identify the seven most critical predictors that resulted in the best prediction performance. Their findings have implications for the design of in-vehicle monitoring and alert systems to facilitate the interaction between the drivers and the automated vehicle.

In [A24], Karim *et al.* create a novel attention-based deep neural network that learns to select the most informative spatial and temporal regions from the input video stream to classify the accident risk of the scene to be seen shortly. The article further introduces a late fusion method to integrate network variants for improving the anticipation ability.

In [A25], Fang *et al.* propose a self-supervised consistency learning framework for traffic accident detection in driving scenarios. It involves the appearance, motion, and context consistency learning, and is inferred by a collaborative multi-task consistency learning framework. The key formulation is to find the inconsistency of video frames, object locations and the spatial relation structure of the scene temporally between different frames captured by the dashcam videos.

In [A26], Sánchez *et al.* propose a new method for situation-aware drivable space (SDS) estimation combining multiple information sources, which is also suitable for AVs equipped with inexpensive sensors. Depending on the situation, semantic information of sensed objects is combined with domain knowledge to estimate the drivability of the space surrounding each object. These estimates are modeled as probabilistic graphs to account for the uncertainty of information sources, and an optimal spatial configuration of their elements is determined via graph-based simultaneous localization and mapping (SLAM).

In [A27], Raja *et al.* propose a Blockchain-integrated Multi-Agent Deep Reinforcement Learning (Block-MADRL) architecture for enhancing the efficiency of CACC while cooperatively detecting attacks, reducing the fuel efficiency of identified attackers and securely notifying the overall network. Their approach uses multi-agent deep reinforcement learning to find fuel and throughput optimizing solutions for CACC and a cooperative verification mechanism based on Extended Isolation Forest (EIF) for attack detection. Attacker data are securely stored in a Road Side Unit (RSU) level blockchain, and they design a low-latency, high-throughput consensus protocol for speedy and secure data dissemination.

In [A28], Zhang *et al.* design an autonomous vehicle (AV) motion planning strategy based on motion prediction and V2V communication to consider necessary interactions in real-world AV motion planning systems. Specifically, the perception system and V2V communication module are proposed to provide real-time traffic and vehicular information to the participated AVs. Then, the AV lane-change motion planning problem through the scope of model predictive control-based problem is formulated, as well as the method of learning optimal motion planning by means of a novel deep learning technique.

In [A29], Yu *et al.* propose a frequency feature pyramid network (FFPNet) to extract the multi-scale information. Meanwhile, an attention mechanism is adopted to strengthen the extraction of different scale information. Moreover, a novel loss function, namely, global–local consistency loss, is presented to address both imbalanced data distribution and insufficient local patterns. Furthermore, a novel crowd-and-vehicle dataset (CROVEH) containing both crowd-and-vehicle annotations is also presented in this article.

We would like to express our sincere thanks to all the authors for submitting their articles and to the reviewers for their valuable comments and suggestions that significantly enhanced the quality of these articles. We are also grateful to the Editor-in-Chief, Prof. Azim Eskandarian, for the great support throughout the whole review and publication process of this Special Issue, and, of course, all the editorial staff. We hope that this Special Issue will serve as a useful reference for researchers, scientists, engineers, and academics in the field of autonomous vehicles.

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APPENDIX: RELATED ARTICLES

[A1] Y. Li, S. Yang, Y. Zheng, and H. Lu, "Improved point-voxel region convolutional neural network: 3D object detectors for autonomous driving," *IEEE Trans. Intell. Transp. Syst.*, early access, May 25, 2021, doi: 10.1109/TITS.2021.3071790.

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