Guest Editorial Introduction to the Special Issue on AI-Empowered Trajectory Analytics in Intelligent Transportation Systems

WITH the rapid growth of location sensing in the Internet of Things (IoT) and Internet of Vehicles (IoV) techniques, trajectory data has been generated that can be used to describe diversity and characteristics of moving objects. The analysis and management of trajectory patterns has become an important issue in recent decades, as it supports efficient strategies and decisions based on discovered patterns and knowledge from the mobility behavior of customers or citizens in many fields and applications (e.g., smart city, intelligent transportation, location-based services, health management, etc.). Since the recent development in AI, it is possible to use AI-based techniques to analyze trajectory data at an unprecedented scale to address applicable issues of effectiveness, efficiency, accuracy, and privacy in Intelligent Transportation Systems (ITS), therefore, it is a highly competitive area to propose innovative methods, principles, procedures, techniques, frameworks, theories, and applications to address the aforementioned challenges of trajectory data in ITS. This Special Issue is intended to provide a forum for all researchers from academia and industry to share their original, creative, innovative, cutting-edge insights, theories, ideas, and developments for the analysis of trajectory data using AI-empowered techniques in ITS. In this special issue, we received 52 submissions, and finally accepted 17 articles to be published in the special issue. Below is a brief introduction to each of them.

In [A1], Alkinani et al. developed a new empirical intelligent XGboost (EIXGB)-enabled logistic transport system at the edge of the network to analyze data efficiently. Moreover, the proposed EIXGB technique aims to provide real-time results based on monitoring parameters of public traffic management systems with higher accuracy and minimal errors. Comprehensive simulation results show the efficiency of the proposed EIXGB technique over standard machine learning techniques using a range of parameters. As the simulation results show, the proposed technique achieves 87%–97% accuracy for the different feature sets of a real-time dataset.

In [A2], Mou et al. implemented a fault diagnosis model of an intelligent dispatch energy storage system based on a Deep Belief Network (DBN) and simulate and analyze the model, which provides an experimental basis for the operation and fault detection of an intelligent dispatch energy storage system.

In [A3], Kong et al. developed a self-driven learning model to solve a mixed-integer programming problem. Considering the convex function constraints related to nonlinear energy consumption, customer demand, and service time windows, the generated pointer network combined with an attention mechanism can derive reward computation via a feed-forward delivery data unit to improve the optimization performance of the trajectory. The experimental results show that the proposed method performs significantly better than exact algorithms and classical heuristics in trajectory optimization.

In [A4], Teng et al. designed a trajectory planning method for deformable objects such as cables, fabrics, and bags. Based on the generated expert demonstration, the agent is offered to learn the state sequence and then imitate the expert's trajectory sequence, which avoids hyper-DOF and nonlinear dynamics of multidimensional deformable objects. The results show that the proposed method can learn effective trajectory planning strategies for various tasks with multidimensional deformable objects.

In [A5], Chen et al. proposed an ensemble framework for extracting vehicle speeds from port-like surveillance videos to analyze AGV moving trajectory. First, the system uses the position of the vehicle in each image via a scale descriptor with extended features. Second, the authors match the vehicle position and trajectory data from the previous step using the Kalman filter and the Hungarian algorithm to obtain image trajectory of the vehicle frame by frame. Third, using the theory of perspective projection, the authors estimate the velocity of motion of the vehicle in the real world. The experimental results indicate that the authors' proposed framework can provide accurate vehicle kinematic data in typical port traffic scenarios, considering that the average measurement error of the mean square deviation is 0.675 km/h, the mean absolute deviation is 0.542 km/h, and the Pearson correlation coefficient is 0.9349. The research results suggest that state-of-the-art AI and computer vision techniques can accurately extract data about on-site vehicle trajectories from port videos, helping port traffic participants make more reasonable management decisions.

In [A6], Asim et al. presented a multi-intelligent reflecting surface (IRS)- and multi-unmanned aerial vehicle (UAV)-assisted mobile edge computing (MEC) system for 5G/6G networks. In the system under study, multiple UAVs are integrated to provide services to large user equipment

Digital Object Identifier 10.1109/TITS.2023.3256239

(UEs) using multiple IRSs. This authors aim to minimize the total cost including energy consumption, completion time, and maintenance cost of UAVs by jointly optimizing the trajectories of UAVs and the phase shifts of the IRSs. In solving this problem, one must consider the deployment of UAVs' stopping points (SPs) and take into account the connection between UEs and UAVs (i.e., which UE sends data to which UAV at which SP), the order of the SPs, and the phase shifts of the IRSs. Therefore, conventional optimization techniques cannot efficiently solve the above problem. To solve the above problem, the authors propose an algorithm called TPaPBA, which consists of four phases. In the first phase, the deployment of SPs is optimized using a differential evolution algorithm with variable population size. In this way, all SPs of UAVs can be determined. Then, in the second phase, the connection between UEs, SPs, and UAVs is optimized. TPaPBA first applies a clustering algorithm to optimize the association between SPs and UAVs, and then a proximity criterion is introduced to optimize the association between UEs and SPs. Then, in the third phase, a low-complexity greedy algorithm is used to optimize the order of SPs for UAVs. Finally, the phase shifts of the IRSs are optimized to improve the data rate between UEs and UAVs.

In [A7], Lai et al. proposed a model for learning spatio-temporal features on edge cloud to achieve high precision and efficiency in traffic flow prediction. The proposed method divides the entire traffic network into several parts and assigns them to the corresponding RSUs for training, which facilitates modeling and training and reduces the load on the central server. Moreover, a small feature extraction model tailored to RSUs is used to learn the spatio-temporal dependency of the traffic network. The experimental results show that the proposed model performs well compared to five baseline methods on two real datasets.

In [A8], Wei et al. considered that the vehicle-oriented IoT is a new generation of IoT networks, thus a secure and feasible data transmission mechanism for delay-free delivery of packets from sensors is an essential component in the development of such IoV networks. In this case, the network should not be vulnerable if some nodes (e.g., vehicles) and channels are corrupted, and the rest of the network should allow data transmission. The fractional critical deleted graph (FCDG) used in graph theory can act as a fractional factor (FF) in the IoV networks to keep the IoT network stable and connected when part of the data transmission network is damaged. In this article, the relationship between toughness and FCDG in IoV networks is investigated. Moreover, the graph constraints are considered along with the tight lower bound of the toughness for the existence of the path factor.

In [A9], Chaeikar et al. presented a key management method called AI-enabled and Layered Key Management (ALKM), which uses an AI approach and a layered workflow to reduce network traffic and workload. ALKM distributes dynamic, synchronous, time-dependent keys between roadside units (RSUs) instead of static cryptographic keys. ALKM provides three layers of secure communication: public, tunnel, and hierarchy. The public layer creates an apartment, a secure layer between the traffic management center (TMC) and all RSUs. Using AI capabilities, the tunnel layer predicts short- and long-term congestion areas by analyzing collected trajectory data, and then establishes a secure communication channel between the selected RSUs and the TMC. In the hierarchy layer, the TMC and the higher-level RSUs assist the lower-level RSUs in decoding messages. The authors extensive analysis shows that, overall, ALKM generates between 48% and 99% less network traffic per generated key than the master key method.

In [A10], Raja et al. stated that the immense growth of autonomous vehicles (AVs) and networking technologies have paved the way for advanced intelligent transportation systems (ITS). AVs increase data demand from in-vehicle users, which poses a significant risk to vehicle trajectory data and is extremely vulnerable to security threats. Due to the enormous coverage and complexity of ITS in the V2X environment, it is challenging to describe and detect the trajectory anomalies in urban movement behavior. Most existing systems rely on a limited number of individual detection strategies, such as frequent pattern determination, and have limited accuracy in detecting anomalous trajectories. However, they only focus on outlier detection and do not consider the different patterns of anomalous trajectories. An Efficient Trajectory Anomaly Detection and Classification (ETADC) framework is proposed in a 6G V2X environment. The proposed ETADC framework uses the Deep Deterministic Policy Gradient algorithm (DDPG) to improve accuracy and efficiency by analyzing multiple strategies, namely, travel speed, travel distance, travel direction, and travel time. The result analysis shows that the proposed ETADC technique outperforms the existing systems by 97% accuracy.

In [A11], Hu et al. designed a novel model for spatio-temporal graph convolutional networks via view fusion for trajectory data analysis (STFGCN). The model contains two independent views: structure view and feature view. In addition, a view fusion layer has been developed. It includes an extended graph convolution module and a causal extended module. The extended graph convolution module fully extracts dynamic spatial dependencies, while the causally extended module captures temporal trends. Stacked view fusion layers and a view fusion module perform fusion operations based on the advantages of the two views and efficiently integrate the information from both views. Several experiments were conducted on two real-world datasets of trajectories. The results show that better prediction performance is obtained, especially in the prediction of long-range times.

In [A12], Lee and Ku proposed a recurrent neural network model based on the double attention mechanism to extract spatial and temporal features. The method applied can perform an adaptive combination of local and global features for trajectory data to effectively predict the trend of short-term demand for bikesharing. In addition, the random walk mechanism was used in this study to maintain the local relationships among bikeshare stations in the preprocessing of time series data, which increases the adaptability to the local location changes of different stations.

In [A13], Wang et al. proposed a hierarchical trajectory anomaly detection method for intelligent transportation systems (ITS) using both machine learning and blockchain technologies. More specifically, a hierarchical federated learning strategy is proposed to improve the generalization capability of the global trajectory anomaly detection model through secondary fusion of the multi-domain trajectory anomaly detection model. By integrating blockchain and federated learning, the iterative exchange and fusion of the global trajectory anomaly detection model can be realized through coordinated on-chain and off-chain data access. The experiments show that the proposed system can improve the generalization ability of the trajectory anomaly detection model in different domains while ensuring its reliability.

In [A14], Han et al. proposed a reinforcement learning-based system to design UGV trajectories against malicious radio sources and minimize movement cost. First, the malicious radio source detection and localization models are introduced after the Received Signal Strength Indicator (RSSI) map establishment. Then, the RSSI map-based UGV trajectory design problem is formulated, where both the movement cost and the security risk play a role. To solve the formed problem, the authors propose a reinforcement learning-based trajectory design scheme, whose complexity is analyzed in detail. Finally, experiments are conducted under different parameter settings, and the simulation results evaluate the correctness and effectiveness of the proposed algorithm.

In [A15], Das et al. proposed a secure blockchain-based V2V communication system (BVCS) to enhance security of vehicles and secure data exchange and communication between vehicles. The smart contracts developed by the authors can automatically authenticate users and their vehicles. The algorithms proposed can authenticate users, detect unauthorized access, and establish secure communication between vehicles. The proposed system can improve data security, user privacy, and vehicle security, and create a trustworthy environment in V2V communication systems.

In [A16], Feng et al. stated that a vulnerability-aware task scheduling mechanism was designed and implemented to address the security problem of scheduling sensitive tasks in intelligent transportation systems (ITS). This system supports security and efficient task scheduling through global and local vulnerability assessment of IoT nodes in ITS networks. Managers are provided with a reconfigurable interface to balance privacy and efficiency. By integrating vulnerability assessment and fine-grained access control, more secure and stable ITS nodes can be granted more permissions and participate in the privacy-sensitive task of trajectory analysis, which increases privacy protection at the edges and ultimately improves the efficiency of task scheduling. Based on the presented experiments and analysis, the proposed system is a practical and cost-effective solution to defend insecure tasks such as trajectory analysis.

In [A17], Alam et al. focused on graph-based neural architecture search (NAS) enabling edge AI for intelligent transportation systems. First, a one-shot NAS is used to generate submodels with different sizes. The best submodels created using a one-shot NAS are selected using a graph-based technique to investigate the relationship between robustness to adversaries and model sizes. In addition, a methodology for evaluating the robustness of deep learning models to different model sizes is proposed. Reducing the model parameters increases the robustness of the model under maximum attacks, while increasing the model parameters increases the robustness of the model under minimum attacks. This interesting phenomenon is demonstrated by experimental results on the correlations between network sizes and model robustness. It is possible to understand the robustness of models with different sizes for edge AI transport systems by analyzing the occurrence of attacks. The guest editorial team would like to thank all the authors who submitted their latest research findings to this Special Section. The team would also like to appreciate the valued contributions of the reviewers for taking out time from their busy schedules and giving constructive comments and suggestions to improve the quality of the manuscripts. Finally, the team would also like to acknowledge the guidance from the IEEE ITS Editor-in-Chief Azim Eskandarian and the professional and timely handling of the manuscripts by Editorial Assistant Miriam Snyder.

JERRY CHUN-WEI LIN, *Guest Editor*
Western Norway University of Applied Sciences
5063 Bergen, Norway

GAUTAM SRIVASTAVA, *Guest Editor*
Department of Math and Computer Science
Brandon University
Brandon, MB R7A 6A9, Canada

JHING-FA WANG, *Guest Editor*
National Cheng Kung University
Tainan 701, Taiwan

APPENDIX: RELATED ARTICLES

[A1] M. H. Alkinani, A. A. Almazroi, M. Adhikari, and V. G. Menon, "Artificial intelligence-empowered logistic traffic management system using empirical intelligent XGBoost technique in vehicular edge networks," *IEEE Trans. Intell. Transp. Syst.*, early access, Feb. 1, 2022, doi: 10.1109/TITS.2022.3145403.

[A2] J. Mou, P. Duan, L. Gao, Q. Pan, K. Gao, and A. K. Singh, "Biologically inspired machine learning-based trajectory analysis in intelligent dispatching energy storage system," *IEEE Trans. Intell. Transp. Syst.*, early access, Mar. 8, 2022, doi: 10.1109/TITS.2022.3154750.

[A3] F. Kong, J. Li, B. Jiang, H. Wang, and H. Song, "Trajectory optimization for drone logistics delivery via attention-based pointer network," *IEEE Trans. Intell. Transp. Syst.*, early access, May 2, 2022, doi: 10.1109/TITS.2022.3168987.

[A4] Y. Teng et al., "Multidimensional deformable object manipulation based on DN-transporter networks," *IEEE Trans. Intell. Transp. Syst.*, early access, Apr. 29, 2022, doi: 10.1109/TITS.2022.3168303.

[A5] X. Chen, Z. Wang, Q. Hua, W.-L. Shang, Q. Luo, and K. Yu, "AI-empowered speed extraction via port-like videos for vehicular trajectory analysis," *IEEE Trans. Intell. Transp. Syst.*, early access, Apr. 27, 2022, doi: 10.1109/TITS.2022.3167650.

[A6] M. Asim, M. ELAffendi, and A. A. A. El-Latif, "Multi-IRS and multi-UAV-assisted MEC system for 5G/6G networks: Efficient joint trajectory optimization and passive beamforming framework," *IEEE Trans. Intell. Transp. Syst.*, early access, Jun. 22, 2022, doi: 10.1109/TITS.2022.3178896.

[A7] Q. Lai, J. Tian, W. Wang, and X. Hu, "Spatial–temporal attention graph convolution network on edge cloud for traffic flow prediction," *IEEE Trans. Intell. Transp. Syst.*, early access, Jul. 7, 2022, doi: 10.1109/TITS.2022.3185503.

[A8] W. Wei, J. Shen, A. Telikani, M. Fahmideh, and W. Gao, "Feasibility analysis of data transmission in partially damaged IoT networks of vehicles," *IEEE Trans. Intell. Transp. Syst.*, early access, Jul. 25, 2022, doi: 10.1109/TITS.2022.3190668.

[A9] S. S. Chaeikar, A. Jolfaei, and N. Mohammad, "AI-enabled cryptographic key management model for secure communications in the Internet of Vehicles," *IEEE Trans. Intell. Transp. Syst.*, early access, Aug. 29, 2022, doi: 10.1109/TITS.2022.3200250.

[A10] G. Raja et al., "AI-empowered trajectory anomaly detection and classification in 6G-V2X," *IEEE Trans. Intell. Transp. Syst.*, early access, Aug. 22, 2022, doi: 10.1109/TITS.2022.3197446.

[A11] W. Hu et al., "Spatio-temporal graph convolutional networks via view fusion for trajectory data analytics," *IEEE Trans. Intell. Transp. Syst.*, early access, Oct. 11, 2022, doi: 10.1109/TITS.2022.3210559.

[A12] S.-H. Lee and H.-C. Ku, "A dual attention-based recurrent neural network for short-term bike sharing usage demand prediction," *IEEE Trans. Intell. Transp. Syst.*, early access, Sep. 26, 2022, doi: 10.1109/TITS.2022.3208087.

[A13] X. Wang, W. Liu, H. Lin, J. Hu, K. Kaur, and M. S. Hossain, "AI-empowered trajectory anomaly detection for intelligent transportation systems: A hierarchical federated learning approach," *IEEE Trans. Intell. Transp. Syst.*, early access, Aug. 25, 2023, doi: 10.1109/TITS.2022.3209903.

[A14] Z. Han et al., "RSSI map-based trajectory design for UGV against malicious radio source: A reinforcement learning approach," *IEEE Trans. Intell. Transp. Syst.*, early access, Dec. 16, 2022, doi: 10.1109/TITS.2022.3208245.

[A15] D. Das, S. Banerjee, P. Chatterjee, U. Ghosh, and U. Biswas, "A secure blockchain enabled V2V communication system using smart contracts," *IEEE Trans. Intell. Transp. Syst.*, early access, Dec. 16, 2022, doi: 10.1109/TITS.2022.3226626.

[A16] X. Feng, J. Wu, A. K. Bashir, J. Li, A. Shen, and M. D. Alshehri, "Vulnerability-aware task scheduling for edge intelligence empowered trajectory analysis in intelligent transportation systems," *IEEE Trans. Intell. Transp. Syst.*, early access, Feb. 14, 2023, doi: 10.1109/TITS.2023.3241479.

[A17] M. G. R. Alam et al., "Feature cloning and feature fusion based transportation mode detection using convolutional neural network," *IEEE Trans. Intell. Transp. Syst.*, early access, Feb. 6, 2023, doi: 10.1109/TITS.2023.3240500.

Jerry Chun-Wei Lin (Senior Member, IEEE) received the Ph.D. degree from the Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan, Taiwan, in 2010. He is currently a Full Professor with the Department of Computer Science, Electrical Engineering, and Mathematical Sciences, Western Norway University of Applied Sciences, Bergen, Norway. He has published more than 600 (more than 90 IEEE/ACM TRANSACTIONS) research articles in refereed journals and international conferences and 11 edited books, and holds 33 patents (held and filed three U.S. patents). His research interests include artificial intelligence, big data technologies, optimization, the Internet of Things (IoT) applications, and bioinformatics. He is a fellow of IET (FIET) and an ACM Distinguished Scientist. He is also the Editor-in-Chief of the *International Journal of Data Science and Pattern Recognition* and an Associate Editor of several IEEE/ACM journals, such as IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS, IEEE TRANSACTIONS ON CYBERNETICS, IEEE TRANSACTIONS ON DEPENDABLE AND SECURE COMPUTING, and IEEE JOURNAL OF BIOMEDICAL AND HEALTH INFORMATICS. He was recognized as the most-cited Chinese researcher in 2018, 2019, 2020, and 2021 by Scopus/Elsevier.

Gautam Srivastava (Senior Member, IEEE) received the B.Sc. degree from Briar Cliff University, USA, in 2004, and the M.Sc. and Ph.D. degrees from the University of Victoria, Victoria, BC, Canada, in 2006 and 2012, respectively. He taught for three years with the Department of Computer Science, University of Victoria, where he was regarded as one of the top undergraduate professors in computer science. In 2014, he will be joining a tenure-track position with Brandon University, Brandon, MB, Canada, where he is currently active in various professional and scholarly activities. He was promoted to the rank of Associate Professor in January 2018. He is also active in research in the field of cryptography, data mining, security and privacy, and blockchain technology. In his five years as a research academic, he has published a total of 400 papers in high-impact conferences in many countries and high-status journals (SCI, SCIE) and has also delivered guest lectures on big data, cloud computing, the Internet of Things (IoT), and cryptography at many universities worldwide. He is an Editor of several SCI/SCIE journals (IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS, *Information Sciences*, *AEJ*, and *ISA Transactions*). He has active research projects with other academics in Taiwan, Singapore, Canada, Czech Republic, Poland, and the USA. He has an H-index of 50 which is strong for an early career researcher. He is currently a Guest Editor for IEEE TRANSACTIONS ON FUZZY SYSTEMS and IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS. His research is funded by federal grants from the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Mathematics of Information Technology and Complex Systems (MITACS).

Jhing-Fa Wang received the bachelor's and master's degrees from National Cheng Kung University (NCKU), Taiwan, in 1973 and 1979, respectively, and the Ph.D. degree from the Stevens Institute of Technology, USA, in 1983. He is currently the Chair and Distinguished Professor with the Department of Electrical Engineering, NCKU. He has published about 100 and 60 journal articles in IEEE, SIAM, IEICE, and IEE, and about 300 international conference papers since 1983. Recently, he has explored his research on orange technology. Orange technology refers to a newly evolved interdisciplinary research area for the integration and innovation of health, happiness, and care technologies. The objective of orange technology is to bring more health, happiness, and warming care to the society. His research interests include multimedia signal processing, including speech signal processing, image processing, VLSI system design, and AI robots. He was also the President of Tajen University in 2012 and 2020, the Formal Chair of the IEEE Tainan Section in 2005 and 2009, the Coordinator of Section/Chapter, IEEE Region 10, in 2011 and 2012, and the Industry Liaison-Coordinator of IEEE Region 10 in 2009 and 2011. He was elected as a fellow of IEEE in 1999 for his contribution to "Hardware and Software Co-Design on Speech Signal Processing." He was also the General Chair of ISCAS 2009. He received the Outstanding Researcher Award from the National Science Council in 1990, 1995, 1997, and 2006. He also received Outstanding Industrial Awards from ACER and the Institute of Information Industry and the Outstanding Professor Award from the Chinese Engineer Association, Taiwan in 1991 and 1996, respectively. He also received the Culture Service Award from the Ministry of Education, Taiwan, in 2008, the Distinguished Scholar Award of KT Li from NCKU in 2009, the IEEE Tainan Section Best Service Award in 2011, the Innovation Education Award in 2013 Seoul International Invention Fair, and a Special Award from the 2017 Kuwait International Invention Fair. He was also invited to give the keynote speeches at PACLIC 12 in Singapore, in 1998, UWN 2005 in Taipei, WirlessCom 2005 in Hawaii, IIH-MSP 2006 in Pasadena, USA, ISM 2007 in Taichung, PCM 2008 in Tainan, 2011 ICAST in Dalian, China, 2011 ICSPCC in Xi'an, China, Keer 2012 in Penghu, Taiwan, HIS 2017 in Moscow Region, Russia, and ICOT 2015, ICOT 2016, and ICOT 2017 in Hong Kong, Australia, and Singapore, respectively. He also served as an Associate Editor of IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS and IEEE TRANSACTIONS ON VERY LARGE SCALE INTEGRATION (VLSI) SYSTEMS and the Editor-in-Chief of *International Journal of Chinese Engineering* from 1995 to 2000.