MetaVehicles in the Metaverse: Moving to a New Phase for Intelligent Vehicles and Smart Mobility

Dear All,

Happy New Year!

Welcome to the first issue of the IEEE Transactions on Intelligent Vehicles (TIV) under its second Editor-in-Chief (EIC). As the new EIC and with your helps, my mission is to make IEEE TIV to be the flagship scientific publication and communication platform in the field of intelligent vehicles and smart mobility. For this purpose, I will adapt the following new policy and new schedule in our review process.

1) A DIDO Commitment from EIC: Day In and Day Out – As the EIC, I will aim to process all new submissions in one day.
2) The 15-Week "3-2-2-4" Guideline for Associate Editors (AEs): For all new submissions, tighten our decision timeline to 15 weeks - 3 weeks for the first decision, 2 weeks for the next two decisions, allowing 2 weeks for minor revisions and 4 weeks for major revisions. Limiting up to a maximum of three decisions before reaching a final decision – capping our maximum duration for processing a submission within 15 weeks.
3) Creating a Special Task Force for Overdue Submissions: Overdue submissions will be transferred to a team of top researchers, educators, and practitioners in the field of intelligent vehicles around the world. This "Overdue Squad", will be used to expedite review processes as needed, while keeping professional quality standards. In creating an alternate "fast track," my aim is to establish a mechanism to solve the longstanding overdue issues, so that no one involved in the review process will have any excuse for long overdue under my editorship, including myself, except production problems which are out of our control.
4) Adding a new "Scan the Issue and Beyond" Editorial Feature: I would like to include a new section in my EIC editorials where we can take a minute to sum up the papers within each issue and speak to any thematic or notable new directions or thoughts on intelligent vehicles research and development. My goal here is with this feature to help make our publication more readable, accessible and to increase engagement with our readers, authors, and all interested. I will invite other scholars and experts to contribute.
5) Moving to a monthly publication: I am proposing changing IEEE TIV to be monthly published, with a significant increase in the page budget starting from the next year. With how quickly Intelligent Vehicles and their applications are growing, I believe a monthly cadence is best suited to the scope and development of our field and enabling us to position as a leading academic publication for research and application.

To achieve these, we will start with a simple measurement: TIV's probability of being the first choice of submission in the field of intelligent vehicles is equal or greater than 95%. Yes, I want you to think of our IEEE TIV even before you start to write your paper on any issue related to intelligent vehicles and smart mobility. I will back to you on the state of IEEE TIV and my plan on its future for the next few years after I learning more about it.

I have been an Editor-in-Chief for various academic journals for the last 25 years, and my editorial philosophy is simple and straight: treat all submissions with professional respect, integrity, and quality. I will do the same for IEEE TIV and start to work on my IEEE TIV EIC account tomorrow, i.e., the second day of the year. I can ensure you that our IEEE TIV will enter a new phase of development: Faster Processing, Better Service and Higher Quality.

I would like to take this special moment to thank our founding Editorial Team, especially our Editorial Assistant, Ms. Ceylan Ozguner, for her service and help during the transitional period. My deepest appreciations go to All and the IEEE Support Staff for all the time and effort they've dedicated to the establishment and development of IEEE TIV.

Last but not the least, hope you would enjoy my editorial on parallel driving of metavehicles in metaverse after scanning the issue, a cold thought on a hot topic. Many thanks for your attention, support, and contribution.

I. Scanning the Issue

1. "Real-Time Implementation of Randomized Model Predictive Control for Autonomous Driving" by *Arun Muraleedharan, Hiroyuki Okuda, and Tatsuya Suzuki*

Model predictive control (MPC) using randomized optimization is expected to solve different control problems. However, it still faces various challenges for real-world applications. This paper attempts to solve those challenges and demonstrates

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a successful implementation of randomized MPC on the autonomous driving using a radio-controlled (RC) car. First of all, a sample generation technique in the frequency domain is discussed. This prevents undesirable randomness which affect the smoothness of the steering operation. Second, the proposed randomized MPC is implemented on a Graphics Processing Unit (GPU). The expected GPU acceleration in calculation speed at various problem sizes is also presented. The results show the improved control performance and computational speed that was not achievable using CPU based implementation. Besides, the selection of parameters for randomized MPC is discussed. The usefulness of the proposed scheme is demonstrated by both simulation and experiments. In the experiments, a 1/10 model RC car is used for collision avoidance task by autonomous driving.

2. "A Review of HMM-Based Approaches of Driving Behaviors Recognition and Prediction" by *Qi Deng and Dirk Soffker*

Current research and development in recognizing and predicting driving behaviors plays an important role in the development of Advanced Driver Assistance Systems (ADAS). For this reason, many machine learning approaches have been developed and applied. Hidden Markov Model (HMM) is a suitable algorithm due to its ability to handle time series data and state transition descriptions. Therefore, this contribution will focus on a review of HMM and its applications. The aim of this contribution is to analyze the current state of various driving behavior models and related HMM-based algorithms. By examining the current available approaches, a review is provided with respect to: i) influencing factors of driving behaviors corresponding to the research objectives of different driving models, ii) summarizing HMM related methods applied to driving behavior studies, and iii) discussing limitations, issues, and future potential works of the HMM-based algorithms. Conclusions with respect to the development of intelligent driving assistant system and vehicle dynamics control systems are given.

3. "Design Methodology to Derive Over-Damped String Stable Adaptive Cruise Control Systems" by *Parthib Khound, Peter Will, and Frank Gronwald*

In this paper, we formulate a common design methodology to derive an adaptive cruise control algorithm in order to compensate the effect of the lower level time-lag on the stability. Here the dynamics of the vehicle is approximated by a first order system. The lower level time-lag is referred to the lag associated with the vehicle dynamics to attain the desired condition computed by the adaptive cruise controller. Inclusion of such dynamics reduces the performance of an adaptive cruise control system, both locally and collectively. The solutions presented here can be applied to design a new adaptive cruise control model or to extend any model with velocity dependent spacing function. The derived design method fulfills the over-damped string stability condition in presence of a time-lag in the plant, irrespective of the choice of the equilibrium operating point of linearization. The over-damped characteristic improves both safety and performance. To demonstrate the application of the presented method, two existing models are extended using the derived strategy, viz. the variable time gap and the quadratic range policy. Later the extended models are simulated with rigorous driving conditions, in order to illustrate the improvements in comparison with the respective original models as well as with the extended models using an existing compensation strategy.

4. "Fast and Compact Image Segmentation Using Instance Stixels" by *Thomas Hehn, Julian Kooij, and Dariu Gavrila*

State-of-the-art stixel methods fuse dense stereo disparity and semantic class information, e.g., from a Convolutional Neural Network (CNN), into a compact representation of driveable space, obstacles and background. However, they do not explicitly differentiate instances within the same semantic class. We investigate several ways to augment single-frame stixels with instance information, which can be extracted by a CNN from the RGB image input. As a result, our novel Instance Stixels method efficiently computes stixels that account for boundaries of individual objects, and represents instances as grouped stixels that express connectivity. Experiments on the Cityscapes dataset demonstrate that including instance information into the stixel computation itself, rather than as a post-processing step, increases the segmentation performance (i.e., Intersection over Union and Average Precision). This holds especially for overlapping objects of the same class. Furthermore, we show the superiority of our approach in terms of segmentation performance and computational efficiency compared to combining the separate outputs of Semantic Stixels and a state-of-the-art pixel-level CNN. We achieve processing throughput of 28 frames per second on average for 8 pixel wide stixels on images from the Cityscapes dataset at 1792×784 pixels. Our Instance Stixels software is made freely available for non-commercial research purposes.

5. "The Effect of SprayWater on an Automotive LIDAR Sensor: A Real-Time Simulation Study" by *Jose Roberto Vargas Rivero, Thiemo Gerbich, Boris Buschardt, and Jia Chen*

This paper presents the first of its kind real-time simulation of the effect of spray water on an automotive LIDAR sensor. The simulation is based on physically measurable quantities in order to facilitate its validation and extension. Both the sensor and the environment are simulated using open source software tools: Blender and Cycles, with the objective of facilitating standardization and broader adoption. The parameters required to construct and calibrate the simulation are extracted from real measurements done on a test area and highway covering different water film thicknesses and vehicle speeds. The simulation is validated in different stages, first by comparing the trajectories of the particles with a regular solver and secondly, by the spatial distribution of the virtual and real point clouds with the measurement results. The resulting framework can be easily expanded to cover scenarios that are more complex and other phenomena counterproductive to the performance of a LIDAR sensor like dirt, exhaust gases, snow, rain and fog. The virtually generated point clouds can be used to validate the performance of the software required for the segmentation, classification and tracking of objects generated by the LIDAR sensor, thereby reducing development costs and increasing software quality.

6. "An Optimal Motion Cueing Algorithm Using the Inverse Kinematic Solution of the Hexapod Simulation Platform" by *Mohammad Reza Chalak Qazani, Houshyar Asadi, and Saeid Nahavandi*

The vehicle motion signals is not able to be replicated using the simulation-based motion platform (SBMP) because of the workspace boundaries. The workspace limitations are determined based on the displacement, velocity and acceleration limitations of the actuators. The motion cueing algorithms (MCAs) are introduced to reproduce the motion sensation for the driver of the SBMP same as the real vehicle's driver while keeping the SBMP inside the actuators' limitations. The optimal MCA was developed to decrease the human motion sensation error between the real vehicle's driver and the SBMP's user based on the human vestibular system model using the linear quadratic regulator method. However, the inverse acceleration kinematics model of the SBMPs are not considered in developing optimal MCA to control the displacement, velocity and acceleration of actuators. The lack of inverse acceleration kinematics consideration inside the optimal MCA causes the poor consumption of the SBMP's workspace, as the optimal MCA only considers the boundaries of the SBMP in the Cartesian coordinate system. In this paper, the new optimal MCA based on the inverse acceleration kinematic solution of the SBMP is designed and developed to regenerate the more realistic motion sensation. The validation of the new optimal MCA is performed using Simulink/MATLAB. The outcomes demonstrate that using the new optimal MCA will reach a better motion sensation with less false motion signals in contrast with the existing optimal MCAs.

7. "R-Comm: A Traffic Based Approach for Joint Vehicular Radar-Communication" by *Rohit Singh, Deepak Saluja, and Suman Kumar*

Automotive radar and vehicular communication are the two primary means of establishing an intelligent transportation system. However, both the systems are susceptible to interference. The inter-vehicular interference significantly affects the radar and communication performance, especially in the dense traffic scenarios. In this work, we have shown that lowering down radar range in dense traffic scenario provides twofold advantages; (a) it reduces radar-to-radar interference and, (b) it provides resources to support the vehicular communication. We propose a joint Radar-Communication (R-Comm) algorithm which enables connected vehicles to use a fraction of radar resources for vehicular communication based on the traffic density. Also, two different schemes have been proposed for R-Comm transmission in the sparse and dense traffic scenarios. Further, through simulation results, it is shown that R-Comm benefits both radar and communication systems.

8. "RangeSeg: Range-Aware Real Time Segmentation of 3D LiDAR Point Clouds" by *Tzu-Hsuan Chen and Tian Sheuan Chang*

Semantic outdoor scene understanding based on 3D LiDAR point clouds is a challenging task for autonomous driving due to the sparse and irregular data structure. This paper takes advantages of the uneven range distribution of different LiDAR laser beams to propose a range aware instance segmentation network, RangeSeg. RangeSeg uses a shared encoder backbone with two range dependent decoders. A heavy decoder only computes top of a range image where the far and small objects locate to improve small object detection accuracy, and a light decoder computes whole range image for low computational cost. The results are further clustered by the DBSCAN method with a resolution weighted distance function to get instance-level segmentation results. Experiments on the KITTI dataset show that RangeSeg outperforms the state-of-the-art semantic segmentation methods with enormous speedup and improves the instance-level segmentation performance on small and far objects. The whole RangeSeg pipeline meets the real time requirement on NVIDIA JETSON AGX Xavier with 19 frames per second in average.

9. "Task-Driven RGB-Lidar Fusion for Object Tracking in Resource-Efficient Autonomous System" by *Kruttidipta Samal, Hemant Kumawat, Priyabrata Saha, Marilyn Wolf, and Saibal Mukhopadhyay*

Autonomous mobile systems such as vehicles or robots are equipped with multiple sensor modalities including Lidar, RGB, and Radar. The fusion of multi-modal information can enhance task accuracy but indiscriminate sensing and fusion in all modalities increase demand on available system resources. This paper presents a task-driven approach to input fusion that minimizes the utilization of resource-heavy sensors and demonstrates its application to Visual-Lidar fusion for object tracking and path planning. The proposed spatiotemporal sampling algorithm activates Lidar only at regions-of-interest identified by analyzing visual input and reduces the Lidar 'base frame rate' according to the kinematic state of the system. This significantly reduces Lidar usage, in terms of data sensed/transferred and potentially power consumed, without a severe reduction in performance compared to both a baseline decision-level fusion and state-of-the-art deep multi-modal fusion.

10. "Value of Temporal Dynamics Information in Driving Scene Segmentation" by *Li Ding, Jack Terwilliger, Rini Sherony, Bryan Reimer, and Lex Fridman*

Semantic scene segmentation has primarily been addressed by forming high-level visual representations of single images. The problem of semantic segmentation in dynamic scenes has begun to receive attention with the video object segmentation and tracking problem. While there has been some recent work attempt to use deep learning models on the video level, what is not known is how the temporal dynamics information is contributing to the full scene segmentation. Moreover, most existing datasets only provide full scene annotation on non-consecutive images to ensure the variability of scenes, making it even harder to explore novel methods on video-level modeling. To address the above issues, our work takes steps to explore the behavior of modern spatiotemporal modeling approaches by: 1) constructing the MIT DriveSeg dataset, a large-scale video driving scene segmentation dataset, densely annotated for pixel-level semantic classes with 5000 consecutive video frames, and 2) proposing a joint-learning framework that reveals the contribution of temporal dynamics information in regard to different semantic classes in the driving scene. This work is intended to help

assess current methods and support further exploration of the value of temporal dynamics information in video-level scene segmentation.

11. "Online Optimization of Gear Shift and Velocity for Eco-Driving Using Adaptive Dynamic Programming" by *Guoqiang Li, Daniel Gorges, and Meng Wang*

In this paper a learning-based optimization method for online gear shift and velocity control is presented to reduce the fuel consumption and improve the driving comfort in a car-following process. The continuous traction force and the discrete gear shift are optimized jointly to improve both the powertrain operation and the longitudinal motion. The problem is formulated as a nonlinear mixed-integer optimization problem and solved based on adaptive dynamic programming. A major difference compared to existing approaches is that the developed control method is model-free, i.e. it does not rely on vehicle models. It can address system nonlinearities and adapt to changes in engine characteristics (e.g. consumption map) during vehicle driving. The computation is efficient and enables possible real-time implementation. The proposed control method is studied for an urban driving cycle to evaluate the control performance with respect to the fuel economy and the driving comfort. Simulations indicate that the host vehicle can reduce the fuel consumption by 5.03% and 1.12% for two consumption maps in comparison to the preceding while keeping a desired inter-vehicle distance. The results further show a decrease of 1.59% and 2.32% in fuel consumption compared to a linear quadratic controller with the same gear shift schedule.

12. "Longitudinal Control of Autonomous Vehicles Consisting Power-Train With Non-Linear Characteristics" by *Elif Toy Azzaghdam and Orhan Behic Alankus*

The autonomous vehicle studies recently have been accelerated to ensure more secure, efficient, and comfortable transportation. Non-linearity in the power-train makes longitudinal control of autonomous vehicles difficult at low speeds. Additionally, rapid acceleration and deceleration (due to the behavior of the surrounding vehicles) increase complexity in control of such systems. In this study, we designed a novel longitudinal controller including the reverse plant model of the vehicle to overcome these problems. The complete controller is designed using parameters known to OEMs (Original Equipment Manufacturer) with vehicle CAN bus signals. The longitudinal controller consists of two parts: The outer controller which determines the target speed according to lead vehicle's speed and the inner controller which determines the accelerator pedal percentage and brake requests. The inner controller includes PI followed by the reverse plant model with a virtual load sensor. This model enables control of a vehicle with non-linear power-train. The designed controller performance was tested on a city bus with a diesel engine and automatic transmission. Vehicle test results proved, that the designed controller is capable of controlling an autonomous vehicle with nonlinear power-train dynamics with onboard computational capacity even at low speeds.

13. "Position Uncertainty-Tolerant Cooperative Merging Application for Mixed Multilane Traffic" by *Nigel Williams, Guoyuan Wu, and Matthew Barth*

To date, numerous cooperative merging techniques have been developed, with multiple studies demonstrating their potential to improve traffic safety, efficiency, and environmental impact at merging points. However, many of these techniques make assumptions that will almost certainly be questionable in the real world, namely: 1) relative positioning between vehicles will be sufficiently accurate at all times; 2) the merging application-equipped vehicles will not change lanes before reaching the merge point, nor will other vehicles change lanes into their lane; and 3) vehicles with merging-assist technology will not mix with vehicles without the technology. This paper proposes a cooperative merging application which is capable of functioning even when the vehicle's positioning accuracy is severely degraded and all vehicles are free to change lanes into and out of the merging traffic streams. Furthermore, our strategy demonstrates safety, efficiency, and environmental benefits for the overall traffic stream even with technology penetration rates as low as 20%.

II. Parallel Driving of MetaVehicles in Metaverse: A Short Story for a Long History

Right after Facebook CEO Mark Zuckerberg changed the name of his company into Meta just before the last Halloween, instantly the term metaverse becomes a red-hot buzzword across the world. Many people asked me: What is a metaverse? Hope or Hype? "Trick or Treat?"

To me, A Treat! Since I am convinced that metaverses, mirror worlds, shadow systems, digital twins, parallel systems, and likes, are just a reflection of the coming revolution of intelligent industries. The true nature of those intelligent technologies is to turn "attention" and "trust" into commercial commodities of mass production and mass circulation, as illustrated by the initial success and rapid or phenomenal growth of new companies around the world, such as FLAG in USA and BAT/TMD in China. This is a historical breakthrough against Herbert Simon's curse, as the founding father of Artificial Intelligence had famously claimed: Attention and trust are the two things that cannot become commodities, because they could not be massively produced and massively circulated due to the inherent limitation in human cognitive capacity, as suggested by Miller's Number for individual attention or Dunbar's Circle for social trust. For us at TIV, this is a technological victory of AI, Robotics, Blockchain, Knowledge Automation, Intelligent Vehicles, and Intelligent Transportation Systems.

My conviction on this has a long history, rooted in my early-career research of using Monte Carlo methods for estimating the fatigue life of various metals with cracks in 1982 and applying Gaussian random fields for evaluating the variation distribution of fundamental frequencies of plates and shells with geometrical imperfections in 1983. This was the seed for my work on computational experiments, shadow systems, and parallel intelligence in 1990s, 2000s, 2010s, and today, especially my research on Cyber-Physical-Social Systems (CPSS), and Parallel Driving and Parallel Testing of Parallel Vehicles in CPSS. To me, metaverses are specific realizations of CPSS, we need meta-vehicles or parallel vehicles of virtual-real interaction for

driving in metaverses for intelligent transportation and smart mobility.

For this end, we need to study and build six types of intelligent vehicles that would drive our societies into smart ones, from "6V" to "6S": Cognitive Vehicles and Parallel Vehicles for vehicular science and technology, Crypto Vehicles and Federated Vehicles for vehicular operation and management, and Social Vehicles and Ecological Vehicles for vehicular ethics and our sustainability, and those 6Vs would make our societies Safe in the physical world, Secure in the cyberworld, Sustainable in the ecological world, Sensitive to individual needs, Servable for all, and Smart in all. Blockchains, smart contracts, DAOs, Web 3.0, Mobile Intelligent Spaces, Brain Computer and Human Machine Interfaces, New Driving Mechanism and Green Power Systems will be key technologies and methods for intelligent vehicles in this 6V to 6S transformation.

Call for Participation: Decentralized Hybrid Symposia for IEEE TIV

Starting with this issue, I will organize decentralized and hybrid workshops or symposia (DHW or DHS) on various issues in Intelligent Vehicles. Welcome to participate in our investigations on-line or off-line in CPSS. Our discussions will be summarized and reported in our Scan the Issue and Beyond at IEEE TIV. Any suggestions or proposals for topics are greatly appreciated.

Let's Drive into the Future with Intelligent Vehicles, from here at IEEE TIV!

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Fei-Yue Wang (Fellow, IEEE) received the Ph.D. degree in computer and systems engineering from Rensselaer Polytechnic Institute, Troy, NY, USA, in 1990. In 1990, he joined the University of Arizona, Tucson, AZ, USA, and became a Professor and the Director of Robotics and Automation Laboratory and the Program in Advanced Research for Complex Systems. In 1999, he founded the Intelligent Control and Systems Engineering Center, Institute of Automation, Chinese Academy of Sciences (CAS), Beijing, China, under the support of Outstanding Chinese Talents Program from State Planning Council, and in 2002, he was appointed as the Director of the Key Laboratory of Complex Systems and Intelligence Science, CAS, and the Vice President of the Institute of Automation, CAS, in 2006. In 2011, he became the State Specially Appointed Expert and the Founding Director of the State Key Laboratory for Management and Control of Complex Systems. He has been the Chief Judge of Intelligent Vehicles Future Challenge since 2009 and the Director of China Intelligent Vehicles Proving Center with Changshu, since 2015. He is currently the Director of Intel's International Collaborative Research Institute on Parallel Driving with CAS and Tsinghua University, Beijing, China.

His research interests include methods and applications for parallel intelligence, social computing, and knowledge automation. He is a Fellow of INCOSE, IFAC, ASME, and AAAS. In 2007, he was the recipient of the National Prize in Natural Sciences of China, numerous best papers awards from IEEE Transactions, and became an Outstanding Scientist of ACM for his work in intelligent control and social computing. He was the recipient of the IEEE Intelligent Transportation Systems Society outstanding Application and Research awards in 2009, 2011, and 2015, respectively, the IEEE Systems, Man, and Cybernetics Society Norbert Wiener Award in 2014, and became the IFAC Pavel J. Nowacki Distinguished Lecturer in 2021.

Since 1997, he has been the General or Program Chair of more than 30 IEEE, INFORMS, IFAC, ACM, and ASME conferences. He was the President of the IEEE Intelligent Transportation Systems Society from 2005 to 2007, IEEE Council of RFID from 2019 to 2021, Chinese Association for Science and Technology, USA, in 2005, American Zhu Kezhen Education Foundation from 2007 to 2008, Vice President of the ACM China Council from 2010 to 2011, Vice President and Secretary General of the Chinese Association of Automation from 2008 to 2018, and Vice President of IEEE Systems, Man, and Cybernetics Society from 2019 to 2021. He was the Founding Editor-in-Chief (EIC) of the *International Journal of Intelligent Control and Systems* from 1995 to 2000*, IEEE Intelligent Systems Magazine* from 2006 to 2007, IEEE/CAA JOURNAL OF AUTOMATICA SINICA from 2014 to 2017, China's *Journal of Command and Control* from 2015 to 2021, and *Chinese Journal of Intelligent Science and Technology* from 2019 to 2021. He was the EIC of the IEEE INTELLIGENT SYSTEMS from 2009 to 2012, IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS from 2009 to 2016, IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS from 2017 to 2020. He is also the President of CAA's Supervision Council, and the new EIC of the IEEE TRANSACTIONS ON INTELLIGENT VEHICLES.