Journal of Dynamic Systems, Measurement, and Control

Guest Editorial

Special Issue on "Autonomous Mobile Systems" in Memory of Professor J. Karl Hedrick

Professor J. Karl Hedrick's professional work was systematically concentrated on the development of nonlinear control theory and on its application to a broad variety of systems, including automated highway systems, formation flight of autonomous vehicles, powertrain control, embedded software design, and active suspension systems. The engineering society lost a profound researcher and intellectual who was a remarkable colleague, mentor, collaborator, contributor, and friend with many in the ASME Dynamic Systems and Control Division, ASME JDSMC editors and readers, and National Academy of Engineering. This JDSMC Special Issue is a grateful response of our engineering community to honor Professor Hedrick's contribution to profession.

The 21st century has been principally changing transport systems of three mediums of vehicle operation on the Earth—ground, air, and water. Autonomy, connectivity, electrification, and intelligent road and off-road mobility have become a dominant core of research and engineering for virtually all vehicle applications. New technological paradigm shifts in vehicles and vehicle systems could feasibly emerge due to incoming interpervasion and transdisciplinary convergence of applied technical, natural, and social sciences and engineering fields. Such rapidly expanding research frontiers require innovative approaches to all areas of autonomous vehicle dynamics and autonomous system conceptual design to make them receptive to technological novelties.

At the same time, a historically formed approach to autonomous vehicle as an electronics-based control system with less emphasis on engineering design for control, vehicle performance, and energy efficiency has required a transformative research effort to advance vehicle design and, thus, to profoundly improve vehicle effectiveness and efficiency. One of the primary steps in this direction is to overcome the boundaries of different physics domains of autonomous vehicles' subsystems and to study and design the vehicles as the entire engineering object, in which subsystems should complement each other actions and act together as one whole thing with no boundaries between the domains. Furthermore, the lacking of in-depth studying of actual dynamic interactions of autonomous vehicles with multiphase media/environment, which has become in many cases a subject matter of specialized journals, has led to publications on autonomous vehicles that turn more to basic research and have less connection to practical design of vehicles and systems.

This Special Issue specifically targets new research areas of autonomous mobile systems in strong connection with transdisciplinary knowledge that would support to outline new directions in multidomain design of vehicles that operate on the ground, in the air, and under the water.

Ground Systems

The research paper contributed by *M. Ghasemi* and *X. Song* is on powertrain control and management for multiple autonomous hybrid vehicles. The work proposes a computationally efficient framework to optimize the multivehicle coordination control and hybrid powertrain energy management at two levels. The optimization problem is formulated into a set of algebraic equations enabling real-time implementation of the algorithms. Stability analysis of the method is given by a statistical method. Simulations on off-road applications were provided to show the effectiveness and robustness of the approaches.

In a paper by *J. T. Cook*, *L. E. Ray*, and *J. H. Lever*, the authors present a generalized approach to multibody modeling of a tracked vehicle with a towing winch along with control strategies to improve vehicle mobility by regulating track slippage. Importantly, the proposed method is based on real-time terrain characterization.

Information on the tire–road interaction is crucial for autonomous cars, especially, the information about the friction confident and the tire–road forces. The paper written by *Shuo Cheng*, *Ming-Ming Mei*, *Xu Ran*, *Liang Li*, and *Lin Zhao* proposes an adaptive unified monitoring system to simultaneously observe the tire–road friction coefficient and the tire forces, including the normal, longitudinal, and lateral forces. Such observation is built on an adaptive unified sliding mode observer that observes first the normal tire force and then goes to the longitudinal and lateral forces, are estimated by adaptive unified sliding mode observer. Then, the road–tire friction coefficient is observed through a designed mode-switch observer. The observer operates in two modes. When the vehicle is under in the driving or braking mode, a slip slope method is used, and a recursive least-squares identification method is utilized in the slip slope method. When the vehicle is under steering, a friction estimation method is applied. The paper demonstrates the effectiveness of the proposed combination of methods.

In the paper written by *Niket Prakash*, *Anna Stefanopoulou*, *Youngki Kim*, and *Matthew Brusstar*, the authors exploited an optimal velocity trajectory that minimizes fuel consumption. Two typical approaches to drive the cycle optimization are velocity smoothing and traction energy minimization. Utilizing an experimentally validated full vehicle simulation software, the paper demonstrates that for conventional gasoline vehicles the lower energy velocity trajectory can consume as much fuel as the velocity smoothing case. This implies that the easily implementable, a vehicle agnostic velocity smoothing optimization can be used for the velocity optimization rather than the nonlinear tractive energy minimization that has been extensively used in the literature.

H. Abbas, *Y. Kim*, *J. B. Siegel*, and *D. M. Rizzo* collectively present their work on speed profile optimization analysis for electric ground vehicles using Pontryagin's maximum principle. The work addresses the problem of finding the energy-efficient electric vehicle speed profiles for given route information including road grades. Five operating modes are found to be sufficient to achieve the minimum vehicle energy consumption in a route. The optimal vehicle velocity profiles can be calculated via Dynamic Programming in distance domain. The work provides some helpful insights into electric vehicle design such as battery sizing and vehicle operational scheduling.

Object detection for autonomous vehicles is studied in this paper by Michael Person, Mathew Jensen, and Anthony Smith, where the focus is on the gap in convolution neural network methods between those that provide high detection accuracy but do not perform inference in real-time, and those that perform inference in real-time, but detection accuracy is low. They define a multimodal fusion detection system and test this system using LiDAR and imagery inputs on ground vehicle mobility class problem set. The results provide insight into the potential advantages of this fusion and the associated operational implications in terms of processing characteristics and detection performance.

In this paper, *Hui Yin*, *Ye-Hwa Chen*, and *Dejie Yu* describe and simulate a control method for an underactuated two-wheel mobile robot, simplified to a pendulum supported on the axle of a single wheel. This robot has two degrees-of-freedom but only one actuator, and thus is a challenge for conventional control engineering. Their method uses a constraint following approach, which is applied to motions with holonomic and nonholonomic constraints related to the orientation of the pendulum to the motion of the wheel. The simulation results are provided showing the successful response of the two constraint following methods.

Soovadeep Bakshi, *Tianheng Feng*, *Zeyu Yan*, and *Dongmei Chen* described in their paper an efficient and fast-scheduling method for handling large numbers of autonomous mobile robots in an industrial environment with physical and task constraints while implementing a priority scheme. In contrast to traditional search approaches which can yield optimal results but can be impractically slow, their two step method first clusters tasks and then uses a model-based learning method to enhance the control update rate for this important class of unmanned vehicle applications.

Aerial Systems

In the paper written by Jay Patrikar, Venkata Ramanna Makkapati, Anay Pattanaik, Hardik Parwana, and Mangal Kothari, the authors have proposed a guidance law for unmanned aerial vehicles (UAVs) that is based on pursuit plus line-of-sight guidance law. The proposed method incorporates inertial speed for computing the acceleration commands which provides adaptive capability to respond to change in vehicle speed due to external disturbances. The paper presents analysis of the proposed method in the framework of Lyapunov and demonstrates the performance via a number of simulated and real-world experiments.

In the paper written by Oladapo Ogunbodede, Souransu Nandi, and Tanuraj Singh, the authors have presented a method for generating optimal UAV trajectories based on the concept of differential flatness. Motivated by energy efficiency attributed to periodic locomotory behavior of powered-coasting-powered seen in birds and marine animals, the proposed method is shown to improve the endurance and range via simulation studies. The paper also uses the Π test to verify the existence of a periodic solution that outperforms the steady-state solution.

In the paper written by Nan Li, Anouck Girard, and Ilya Kolmanovsky, the authors have presented a two-layer framework for autonomous vehicle control. In this framework, the decision-making/behavior planning problem of the vehicle in dynamic and uncertain condition is formulated as a partially observable Markov decision process with time-joint chance constraints and is solved via a stochastic predictive control algorithm. The planned behavior is then executed using a nonlinear model predictive control approach.

As *Mohammad Sarim*, *Mohammadreza Radmanesh*, *Matthew Dechering*, *Manish Kumar*, *Ravikumar Pragada*, and *Kelly Cohen* emphasized in their paper, the management of UAV traffic becomes quite challenging due to issues such as real-time path planning of large number of vehicles, communication delays, operational uncertainties, failures, and noncooperating agents. To address this challenge, the paper presented a novel UAV Traffic Management architecture that enables an integration of UAVs the National Airspace System. The method is built on initial path planning of multiple UAVs and an algorithm that is based on the concept of resource allocation using a market-based approach. The study proved the scalability, optimality, and ability of the proposed approach to provide feasible solutions.

In the paper written by Xiang He, Gordon Kou, Marc Calaf, and Kam Leang, the authors have proposed a modeling and control approach to address the disturbance caused by in-ground-effect (IGE) on multirotor UAVs. The authors have proposed an exponential model to predict the IGE, and have analyzed and validated the model using an experimental quadcopter UAV. Subsequently, a model-based feed-forward controller and a nonlinear disturbance observer are designed to compensate for the IGE and enhance the closed-loop control. Experimental studies are carried to validate the performance of the controller.

Underwater Systems

Maria Casta's and *Xiaobo Tan's* paper is concerned with a nonlinear model predictive control for a tail-actuated robotic fish. The proposed method accommodates the nonlinear dynamics and actuation constraints while minimizing the control effort and providing efficient computing to identify the model parameters that is based on the measured swimming and turning data for the robot-fish. Additionally, a control projection method is introduced to accommodate the sector-shaped constraints of the control inputs and, simultaneously, to minimize the optimization complexity in solving the nonlinear model predictive control problem. Both simulation and experimental results support the effectiveness of the proposed approach and method.

The paper by *Z. Chen*, *P. Hou*, and *Z. Ye* is focused on a novel hybrid tail actuation mechanism for robotic fish. Consisting of two active joints, the tail uses a servomotor to produce the primary propulsion and exploits a soft and lightweight ionic polymer–metal composite actuator for the second joint to enable steering. The authors present a dynamic model for the robotic fish with the proposed tail, which captures the ionic polymer–metal composite dynamics, hydrodynamic forces and moments produced by the tail, and the dynamics of the body. The experimental results with a robotic fish prototype are presented to evaluate the swimming and turning performance of the design and to validate the presented dynamic model.

Flow estimation is of significant interest in the control of underwater vehicles or robots. In their paper, *F. Dang* and *F. Zhang* investigated the estimation of the flow field based on the pressure difference measurements from multiple sensors mounted on a robot, using a recursive Bayesian approach. In particular, reduced-order modeling through proper orthogonal decomposition is used to capture the flow field. The authors discuss several key issues related to the estimation and sensor placement, and use two simulation examples to illustrate the estimation approach. The paper concludes with a closed-loop control example based on the flow estimation, where the angle of attack of the robot is driven to zero.

Xiongfeng Yi and Zheng Chen introduce a robust visual object tracking method for unmanned system perception that projects image pixels into real-world coordinates for recognition algorithms to operate on. Performance of the system under conditions of partial blockage of the objects or reflections. The results are provided for submerged objects moving near and into the surface of water.

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