Digital Object Identifier 10.1109/ACCESS.2021.3090135

EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: REAL-TIME MACHINE LEARNING APPLICATIONS IN MOBILE ROBOTICS

In the last ten years, advances in machine learning methods have brought tremendous developments to the field of robotics. The performance in many robotic applications such as robotics grasping, locomotion, human–robot interaction, perception and control of robotic systems, navigation, planning, mapping, and localization has increased since the appearance of recent machine learning methods. In particular, deep learning methods have brought significant improvements in a broad range of robot applications including drones, mobile robots, robotics manipulators, bipedal robots, and self-driving cars. The availability of big data and more powerful computational resources, such as graphics processing units (GPUs), has made numerous robotic applications feasible which were not possible previously.

Despite recent advances, there are still gaps in order to apply available machine learning methods to real robots. Directly transferring algorithms that work successfully in the simulation to the real robot and robot self-learning are among the current challenges. Moreover, there is also a need for new algorithms and more explainable and interpretable models that receive and process data from the sensors such as cameras, light detection and ranging (LIDAR), inertial measurement unit (IMU), and global positioning system (GPS), preferably in an unsupervised or semi-supervised fashion.

This IEEE Access Special Section on Real-Time Machine Learning Applications in Mobile Robotics aims to present works related to the design and usage of recent machine learning methods for robotics applications, focusing on the state-of-the-art methods, such as deep learning, generative adversarial networks, scalable evolutionary algorithms, reinforcement learning, probabilistic graphical models, Bayesian methods, and explainable and interpretable approaches.

The Call for Papers aroused great enthusiasm in the scientific community, and the Special Section received 46 submissions. Out of these, 12 articles were accepted for inclusion after a thorough review process by at least two independent referees. The 12 accepted articles are briefly discussed next.

The article "Waypoint mobile robot exploration based on biologically inspired algorithms," by Kamalova *et al.*, presents novel stochastic exploration algorithms based on whale optimization (WO), grey wolf optimizer (GWO), and particle swarm optimization (PSO) algorithms for the mobile robot system. The proposed exploration algorithms are first applied in the simulation environment generated by the authors, and the obtained results are compared with each other. Then, the GWO algorithm is applied in different real-world environments using the MATLAB-ROS integration tool to show the success of the bio-inspired optimization algorithm in mobile robotics.

The article "Mobile robot localization based on gradient propagation particle filter network," by Zhang *et al.*, proposes a novel gradient propagation particle filter network (GPPFN) for robot localization. GPPFN includes a particle filter and two models called the motion model and the measurement model that are independent of each other. The motion model is used to collect the action of the robot and then to perform the prediction process. The measurement model is mainly based on the images observed by the robot. The particle filter algorithm is used to update the state space.

The article "A data-driven approach for collision risk early warning in vessel encounter situations using attention-BiLSTM," by Ma *et al.*, proposes an approach to collision risk early warning in vessel encounter situations using a novel deep learning technique, including bidirectional long short-term memory (BiLSTM) and attention mechanism. In this approach, BiLSTM is used to extract correlations among behaviors, and the attention mechanism is applied to emphasize the key information relevant to the risk prediction task. Using this approach, effective and real-time risk prediction is accomplished. Some experiments using ship trace data are presented.

The article "Artificial bee colony optimization algorithm incorporated with fuzzy theory for real-time machine learning control of articulated robotic manipulators," by Huang and Chuang, studies real-time machine learning control (MLC) of a six-DOF articulated robotic manipulator. MLC includes the fractional-order proportional-integral-derivative control strategy. The gain parameters of the controller are online tuned via the artificial bee colony (ABC) optimization algorithm empowered with fuzzy theory. The modified ABC with dynamic weight is used to optimize the fuzzy structure and fractional order. In experimental studies, a real-time operating system on a microprocessor is used with the ABC-fuzzy MLC to meet critical timing constraints by considering the dynamics of actuators. The comparative works with the conventional control methods, such as PID and Fuzzy PID, and some popular evolutionary algorithms, such as genetic algorithm (GA) and ant colony optimization (ACO), are presented.

The article "Vision-based moving UAV tracking by another UAV on low-cost hardware and a new ground control station," by Çintaş *et al.*, proposes a low-cost method that detects and tracks moving UAVs in videos using a CPU at about 30 frames per second on an average. The proposed method combines the deep learning-based object detection algorithm YOLO and the tracking algorithm kernel correlation filter.

The article "AMMDAS: Multi-modular generative masks processing architecture with adaptive wide field-of-view modeling strategy," by Desanamukula *et al.*, considers a novel, cost-effective, and highly responsive post-active driving assistance system. This system proposes a vision-based approach processing a panoramic-front view and simple monocular-rear view to generate robust and reliable proximity triggers along with correlative navigation suggestions. The proposed system generates robust objects and adaptive field-of-view masks using famous deep neural networks, and is later processed and mutually analyzed in respective stages to trigger proximity alerts and frame reliable navigation suggestions. The system is tested on their custom-built, different public datasets to generalize its reliability and robustness under multiple wild conditions, input traffic scenarios, and locations.

The article "Developing a lightweight rock-paper-scissors framework for human–robot collaborative gaming," by Brock *et al.*, develops a novel framework for a social and entertaining rock–paper–scissors play interaction between a robot and a human player. The gesture recognition is done via a leap motion device and two separate machine learning architectures to evaluate kinematic hand data on the fly. The proposed framework runs in real-time and provides a basic interactive play experience.

The article "Real-time object navigation with deep neural networks and hierarchical reinforcement learning," by Staroverov *et al.*, studies the problem of indoor navigation using an RGB-D camera in the presence of noise. It proposes a new Habitat-based Instance Segmentation, SLAM, and Navigation (HISNav) framework based on a neural network for a real mobile ground robot platform, including a camera and a LiDAR to control in a fast and resistant way against possible noise in sensors and actuators. The framework combines semantic segmentation, mapping, localization, and hierarchical reinforcement learning methods. This framework applies the sim2real paradigm. It first runs and trains the robot in a simulation environment and then loads the trained models onto a real robot. Experimental studies improve over the existing learning solutions of the object navigation problem in terms of work and learning speed and the solution's quality.

The article "LSTM and filter based comparison analysis for indoor global localization in UAVs," by Yusefi *et al.*, analyzes the problem of global localization for unmanned aerial vehicles (UAVs). The authors propose a sequential deep learning framework based monocular visual–inertial localization system. The framework is generated by convolutional neural networks (CNN) as a visual feature extractor, a small IMU integrator-BiLSTM, and BiLSTM network as a global pose regressor. Moreover, the traditional IMU filtering methods instead of LSTM and CNN are applied to obtain a better time-efficient deep pose estimation framework without degrading the accuracy. The authors compare the different algorithms on indoor UAV datasets, simulation environments, and real-world drone experiments in terms of accuracy and time efficiency.

The article "Bidirectional stereo matching network with double cost volumes," by Jia *et al.*, proposes a real-time stereo matching network that does not require post-processing and generates an accurate disparity map at 25 ms on a GPU. The work generates two different cost volumes through traditional methods and convolutional neural networks. The bidirectional cost aggregation network is a two-branch structure, which can aggregate the above two cost volumes with different network depths.

We are very honored to have the invited article "Collision avoidance in pedestrian-rich environments with deep reinforcement learning," by Everett *et al.*, from the Massachusetts Institute of Technology, USA, which is one of the pioneer players in robust planning and learning under uncertainty with an emphasis on the multiagent system. The authors use deep reinforcement learning as a framework to model the complex interactions and cooperation with nearby decision-making agents, such as pedestrians and other robots. They build up an algorithm applying collision avoidance among a variety of heterogeneous, noncommunicating, dynamic agents without using any particular behavior rules. They introduce a novel strategy using LSTM that enables the algorithm to use observations of an arbitrary number of other agents, instead of a small fixed number of neighbors. They provided the experimental setup with two platforms. The first platform consisting of a fleet of four multirotor shows the transfer of the learned policy to vehicles with more complicated dynamics than the unicycle kinematic model used in training. The second platform consisting of a ground robot operating among pedestrians presents the policy's robustness to both imperfect perceptions from low-cost, onboard perception, and heterogeneity in other agent policies, as none of the pedestrians follows one of the policies seen in training.

We are very honored to have the invited article "Run-time monitoring of machine learning for robotic perception: A survey of emerging trends," by Rahman, *et al.*, from the ARC Centre of Excellence for Robotic Vision, Queensland University of Technology, Australia, which is one of the pioneer players in robotics vision. The authors survey run-time monitoring of learning-based perception systems dominated by deep neural networks. This topic is crucial for robotic applications due to the difficulty in applying design-time formal verification and safety guarantees for such systems, mainly due to their complexity and the complexity of modeling their deployment environments. They exhibit an emerging research direction that centers on run-time verification and monitoring.

Finally, the Editors of the Special Section express their gratitude to the authors for their contributions, to the volunteering referees for their dedication, and to the entire IEEE Access editorial staff for their invaluable support.

AYŞEGÜL UÇAR, *Lead Editor*
Department of Mechatronics Engineering
Firat University
23119 Elâzığ, Turkey

JESSY W. GRIZZLE, *Guest Editor*
Department of Electrical Engineering and Computer Science
Robotics Institute
University of Michigan
Ann Arbor, MI 48109, USA

MAANI GHAFFARI, *Guest Editor*
Department of Naval Architecture and Marine Engineering
Robotics Institute
University of Michigan
Ann Arbor, MI 48109, USA

MATTIAS WAHDE, *Guest Editor*
Department of Mechanics and Maritime Sciences
Division of Vehicle Engineering and Autonomous Systems
Chalmers University of Technology
41296 Gothenburg, Sweden

H. LEVENT AKIN, *Guest Editor*
Department of Computer Engineering
Boğaziçi University
34342 Istanbul, Turkey

JACKY BALTES, *Guest Editor*
Educational Robotics Centre
Department of Electrical Engineering
National Taiwan Normal University
Taipei 10610, Taiwan

H. IŞIL BOZMA, *Guest Editor*
Department of Electrical and Electronic Engineering
Boğaziçi University
34342 Istanbul, Turkey

JAIME VALLS MIRO, *Guest Editor*
School of Mechanical and Mechatronic Engineering
Robotics Institute
University of Technology Sydney
Sydney, NSW 2007, Australia

AYŞEGÜL UÇAR (Senior Member, IEEE) received the B.S., M.S., and Ph.D. degrees from the Department of Electrical and Electronics Engineering, Firat University, Turkey, in 1998, 2000, and 2006, respectively. In 2013, she was a Visiting Professor with Louisiana State University, USA. Since 2020, she has been a Professor with the Department of Mechatronics Engineering, Firat University. She has more than 21 years of background in autonomous technologies and artificial intelligence, its engineering applications, robotics vision, teaching, and research. She is active in several professional bodies, in particular, she is a member of the European Artificial Intelligence Alliance Committee and an Associate Editor of IEEE Access and *Turkish Journal of Electrical Engineering and Computer Sciences*.

JESSY W. GRIZZLE (Fellow, IEEE) received the Ph.D. degree in electrical engineering from The University of Texas at Austin, in 1983. He is currently the Director of the Michigan Robotics Institute and a Professor of electrical engineering and computer science with the University of Michigan, where he holds the titles of the Elmer Gilbert Distinguished University Professor and the Jerry and Carol Levin Professor of engineering. He jointly holds 16 patents dealing with emissions reduction in passenger vehicles through improved control system design. He is a fellow of the IFAC. He received the Paper of the Year Award from the IEEE Vehicular Technology Society, in 1993, the George S. Axelby Award, in 2002, the Control Systems Technology Award, in 2003, the Bode Prize, in 2012, the IEEE Transactions on Control Systems Technology Outstanding Paper Award, in 2014, the IEEE Transactions on Automation Science and Engineering Outstanding Paper Award, and the Googol Best New Application Paper Award, in 2019. His work on bipedal locomotion has been the object of numerous plenary lectures and has been featured on CNN, ESPN, Discovery Channel, *The Economist*, *WIRED* magazine, *Discover* magazine, *Scientific American*, and *Popular Mechanics*.

MAANI GHAFFARI received the Ph.D. degree from the Centre for Autonomous Systems (CAS), University of Technology Sydney, NSW, Australia, in 2017. He is currently an Assistant Professor with the Robotics Institute and the Department of Naval Architecture and Marine Engineering, University of Michigan, Ann Arbor, MI, USA, where he recently established the Computational Autonomy and Robotics Laboratory. His research interest includes the theory and applications of robotics and autonomous systems.

MATTIAS WAHDE received the Ph.D. degree in 1997. He was appointed as a full professor in 2015. He is currently a Professor of applied artificial intelligence with the Chalmers University of Technology, Göteborg, Sweden. He has supervised many Ph.D. students and over 100 master theses. In addition to his research work, he also teaches courses on stochastic optimization algorithms and intelligent agents. His main research interests include stochastic optimization algorithms and human–machine interaction, in particular, cognitive models, and their applications in robots, intelligent agents, and autonomous vehicles.

H. LEVENT AKIN received the B.S. degree from the Department of Aeronautical Engineering, Faculty of Mechanical Engineering, Istanbul Technical University, in 1982, and the M.S. and Ph.D. degrees from the Department of Nuclear Engineering, Institute for Graduate Studies in Sciences and Engineering, Boğaziçi University, Istanbul, Turkey, in 1984 and 1989, respectively. He has been a Professor with the Department of Computer Engineering, Boğaziçi University, since 2005. He has Ph.D. and M.Sc. supervisions that are 11 completed, five in progress and 52 completed, and one in progress, respectively. He organized 16 scientific meetings. He has seven edited books, 33 journal articles, 119 conference and workshop papers, and 21 research projects. His main research interests include robotics and artificial intelligence.

JACKY BALTES received the Ph.D. degree in artificial intelligence from the University of Calgary, in 1996. From 1996 to 2002, he worked as a Senior Lecturer with The University of Auckland, Auckland, New Zealand. From 2002 to 2016, he was a Professor with the Department of Computer Science, University of Manitoba, Winnipeg. He has been working as an Outstanding Professor and the Head of the Educational Robotics Center, National Taiwan Normal University, Taiwan, since 2016. His research interests include intelligent robotics, artificial intelligence, machine learning, and computer vision. He has also been a member of the RoboCup Executive Committee, the President of the FIRA Robotic Soccer Association, and the Chair of the HuroCup Competition.

H. IŞIL BOZMA received the B.S. degree (Hons.) in electrical and electronics engineering from Boğaziçi University, Istanbul, Turkey, in 1983, and the M.S. and Ph.D. degrees from Yale University, New Haven, CT, USA, in 1986 and 1992, respectively. Then, she joined the Faculty of Electrical and Electronics Engineering, Boğaziçi University, where she became a Full Professor, in 2004. In 1996, she co-founded the Intelligent Systems Laboratory and has been the Director of the Laboratory ever since. She has been a Visiting Researcher with the Advanced Technology Laboratory, University of Michigan, Ann Arbor, MI, USA, and the School of Engineering and Applied Science, University of Pennsylvania, Philadelphia, PA, USA. She has served as a consultant for industrial projects on sensory-based automation. She has authored or coauthored more than 60 articles in refereed journals or conference proceedings. Her research interests include multirobot systems, robot vision and cognition, attentive robots, and game theory. She received the Francis Erbsmann Award from IPMI, in 1992, the 1997 Texas Instruments European Universities DSP Challenge 2nd Runner-Up Award, the Turkish Electronic Industrialists Society Innovation Award, in 2004, and the Boğaziçi University Academic Incentive Awards.

JAIME VALLS MIRO received the B.Eng. and M.Eng. degrees in computer science (systems engineering) from Valencia Polytechnic University (UPV), Spain, in 1990 and 1993, respectively, and the Ph.D. degree in robotics and control systems from Middlesex University London, U.K., in 1998. He worked in the underwater robotics industry as a software and control systems analyst, in 2003. In 2004, he joined the Centre for Autonomous Systems, UTS, Australia (currently the UTS Robotics Institute), where he is currently an Associate Professor. His areas of interest span across the field of robotics, most notably modeling sensor behaviors for perception and mapping, computational intelligence in HRI—assistive robotics in particular, and robot navigation. In the last few years, he has devoted this interest in pursuing a better understating of condition assessment sensing and robotics for infrastructure maintenance in close collaboration with the water industry.