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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.

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