EDITORIAL

Introduction to the focused section on machine learning, estimation and control for intelligent robotics

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Owing to the explosive advancements in recent years in the areas of computational intelligence, material synthesis, and device integration, a new era of intelligent robotics, featuring unprecedented capabilities of sensing, actuation, and decision making, has arrived. Various newly developed robotic systems have penetrated into virtually all industrial sectors, ranging from manufacturing, energy, aerospace and naval, infrastructure, to health care and service, etc. They possess remarkably enhanced performances in terms of accuracy, adaptivity, reliability, and autonomy, and are poised to change fundamentally our modalities of working and living. The new accomplishments exemplify the collaborative efforts by academia and industry that are currently accelerating.

Aiming at documenting and disseminating the progresses and identifying growth opportunities, this "Focused Section on Machine Learning, Estimation and Control for Intelligent Robotics" of the International Journal of Intelligent Robotics and Applications (IJIRA) showcases a number of recent technological achievements in the learning and control of robotic systems. It includes nine papers that share the common theme of robotic systems utilizing complex or heterogeneous data in their design and control through advanced learning and estimation techniques.

The paper "Robotic Target Following with Slow and Delayed Visual Feedback", by Xiao and Chen, provides a control method for autonomously tracking moving targets with slow and delayed visual feedback. Such capabilities underpin robotic applications ranging from transportation to medical systems. Compared to classic position-based visual servo, the proposed approach achieves 95% reduction of tracking errors when partial knowledge of the target dynamics is known. The result is achieved via a tripartite approach including (1) a velocity control of the robot that ensures exponential reduction of the visual feature error even subject to a maneuvering target, (2) a pose and velocity estimation that considers the dynamics of the moving target, and (3) a multirate information recovery that recovers fast motion estimates from slow and delayed visual feedback.

In "Handling Crowdsourced Data using State Space Discretization for Robot Learning and Synthesizing Physical Skills", Zhao et al. consider the problem of continuous robot learning towards ubiquitous robot physical intelligence. In view of the emerging opportunities in machine learning from large datasets, the authors propose to replicate the success of crowdsourced human computation in robot physical intelligence. Sensorimotor information from a group of teleoperators is collected. The paper then uses a state-space discretization to manage the data and synthesize robot skills. Two types of algorithms are proposed and justified via case studies pertaining to robotic object manipulation.

In "Influence of Human Operator on Stability of Haptic Rendering: A Closed-Form Equation", Mashayekhi et al. present a new formulation for stability analysis of rigid haptic devices in presence of a human operator. This formulation enables the prediction of stability boundaries within large parametric ranges of time delay and virtual damping. The formulation can relate all parameters of the operator's hand, virtual environment, haptic device, sampling time, and time delay in a unified equation. The influence of the operator's hand and effective mass on stability is studied analytically and verified by simulations and experiments on a KUKA lightweight robot.

In "Error Modeling and Sensitivity Analysis of a Parallel Robot with R-$(SS)^2$ Branches", Huang et al. investigate

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the error model of parallel robots with R-(SS)^2 (R, actuated revolute joint; S, spherical joint) branches that are widely used in high-speed sorting. By considering the error transmission mode of the dual-moving platform as a common straight line, a general form of the error model containing all possible geometric errors is established. The sensitive geometric errors are then identified. It is demonstrated that reducing the geometric errors with relatively higher sensitivity values has better effect. The simulation results show that both larger volumetric errors and rotational errors tend to aggregate near the boundaries of the workspace. This improved error modeling method takes the adaptability of the error modeling into account, and can be extended to the specific error modeling of the corresponding robot.

In "Shape Estimation for Elongated Deformable Object using B-spline Chained Multiple Random Matrices Model", Yao et al. propose a B-spline chained multiple random matrix model (RMM) representation to model geometric characteristics of an elongated deformable object. This shape estimation problem is challenging due to the hyper degrees of freedom structure of the elongated deformable object. Based on the likelihood function of the proposed B-spline chained multiple RMM, an expectation–maximization method is derived to estimate the shape of the elongated deformable object. A split and merge method based on the Euclidean minimum spanning tree is proposed to provide initialization for the EM algorithm. The performance of the proposed shape estimation algorithm is evaluated using real measurements of a red dock line in 6 different configurations. The experimental results demonstrate that the B-spline curve chained RMMs algorithm is capable of estimating the shape of the elongated deformable object configured as intersecting and non-intersecting shapes.

The paper "A Recurrent Neural Network for Variable Admittance Control in Human–Robot Cooperation: Simultaneously and online Adjustment of the Virtual Damping and Inertia parameters", by Sharkawy et al., introduces a recurrent neural network for variable admittance control in human–robot cooperation tasks for optimal adjustment of both the virtual damping and the virtual inertia coefficients simultaneously based on online Jordan recurrent neural network (JRNN) training. This network is indirectly trained using the real-time recurrent learning algorithm and based on the velocity error between the reference velocity of the minimum jerk trajectory model and the actual velocity of the robot. The generalization and the effectiveness of the proposed method are illustrated by multiple subjects testing through comparisons with existing methods.

In "Adaptive Formation-Switching of a Multi-Robot System in an Unknown Occluded Environment using BAT Algorithm", Roy et al. propose an adaptive formation control strategy which enables the robots to navigate through the landscape without crashing into obstacles, while maintaining a strong inter-agent cohesiveness and simultaneously switching their formation when situations change. The formation control law is designed based on the echolocation principle of the bio-inspired bat algorithm, and rests on three components: attraction, repulsion, and obstacle avoidance controllers. Extensive simulation and experimental studies have been conducted to validate the proposed scheme.

The paper "Vehicle Specific Robust Traversability Indices Using Roadmaps on 3D Pointclouds" by Khan et al. provides a framework to determine whether a particular segment of the road is traversable for a particular vehicle, by considering the obstacle size, number, and locations. Two indexes, including the Road Traversability Index and the Road Safety Index, have been introduced and analyzed. The proposed analysis framework takes terrain (road and obstacles), vehicle parameters, motion model, and collision criterion into consideration, and leverages the graph-theory approach to infer traversability. This framework has been applied to various real-world scenarios, and it shows the proposed roadmap-based traversability can be used to assess the safety of the road for a particular vehicle.

Lastly, in "Robust State Dependent Riccati Equation Variable Impedance Control for Robotic Force-Tracking Tasks", Roveda and Piga focus on the derivation and validation of a sensorless model-based methodology for high-performance force control demanded by various human–robot interaction applications. Based on sensorless Cartesian impedance control, an Extended Kalman Filter (EKF) has been designed to estimate the physical interaction between the robot and the environment. Such estimation is then used to close a robust high-performance force loop designed by exploiting a variable impedance controller and a State Dependent Riccati Equation (SDRE) force controller. This approach has been validated through simulations on a Franka EMIKA panda robot for a probing task involving materials with different stiffnesses. Simulation results demonstrate the effectiveness of the proposed method in guaranteeing enhanced stability and tracking performance compared with an LQR controller.

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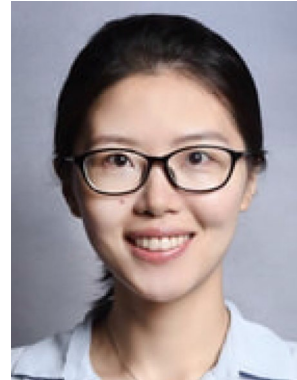
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