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Editorial

Introduction to the special issue on Intelligent Control and Optimisation

It is our pleasure to introduce the special issue on Intelligent Control and Optimisation that we have organised on behalf of the International Federation of Automatic Control (IFAC) Technical Committee on Computational Intelligence and Control (TC3.2). The main topic of the special issue is 'Advances in Machine Learning and AI for Intelligent Control and Optimisation'.

Since the development of the first neuron model by Warren McCulloch and Walter Pitts in 1943 we have seen huge advances in AI and Machine Learning, from the Rosenblatt Perceptron in 1957 and the MLP and backpropagation training algorithm in 1986, to the development of long short-term memory neural networks (LSTMs), Convolutional Neural Networks (CNNs) and Deep Learning methods at the turn of the century (1996–2012). In the last decade the advances have been unprecedented, with breakthroughs in computer vision, natural language processing, and learning (deep reinforcement learning, transfer learning, self-attention mechanism, etc.), that have the potential to be transformative for our society in many areas such as diagnostics in healthcare, autonomy in transport, agriculture and construction, and robotics and digitalisation in manufacturing (Industry 4.0).

Intelligent control and optimisation sit at the interface between AI/Machine learning and the fields of control and optimisation. They encompass methodologies such as neural network-based control, fuzzy control, evolutionary and nature inspired learning and optimisation, and reinforcement learning. As technology continues to advance and we seek to address global challenges around economic, environmental, and social sustainability, the need for intelligent control approaches that can optimally operate complex processes and systems becomes increasingly crucial. However, many challenges limit their wide-scale adoption, from dealing with data quality and volume issues to achieving scalable robust, understandable and safe solutions. This special issue brings together a collection of articles that address these challenges and/or showcase the latest real-world applications and enabling algorithmic advances in Intelligent Control and Optimisation, as they pertain to system identification, intelligent control, and optimisation of dynamical systems.

We solicited contributions for the special issue through an open call to the TC3.2 community and invitations to contributors from the IFAC International Conference on Intelligent Control and Automation Sciences and (ICONS) and the Embedded Systems, Computational Intelligence and Telematics in Control (CESCIT) conference series, held during the IFAC triennium 2020–2023. The call for paper was launched in April 2021 and closed in February 2022. In total, we received 64 submissions, of which 36 were finally selected for inclusion in the special issue. Among these contributions we have six papers addressing topics in path planning and tracking for autonomous vehicles, five papers presenting advances in intelligent Model Predictive Control (MPC), five papers on machine learning and reinforcement learning enhanced control, five papers introducing advances in anomaly detection, fault detection and fault mitigation, six papers making contributions in the area of intelligent optimisation, four papers incorporating AI based approaches in forecasting and prediction, and five papers with algorithmic contributions that enhance the performance of intelligent systems.

1. Path planning and tracking for autonomous vehicles

Jarl et al. (2022) develop an active learning framework to annotate driving trajectory time series data and discover unknown driving scenario trajectories, enabling the creation of annotated driving scenario trajectories that are crucial for verification and validation of autonomous vehicles.

Ivić et al. (2022) develop a finite element solution to the Heat equation based potential field approach for multi-agent autonomous surveying. Their approach offers additional flexibility to existing state-of-the-art methods for surveying arbitrarily shaped areas with obstacles, while incorporating a motion control algorithm that guarantees collision avoidance.

Debarshi et al. (2022) presents an adaptive Radial Basis Function (RBF) neural network-aided longitudinal cruise and lateral path-tracking controller for an autonomous vehicle. The neural network, which is designed to learn model uncertainties and eliminate the effect of unknown disturbances on the road in real time, is coupled with basic PID cruise and Stanley path-tracking controllers to yield robust tracking performance in unknown environments.

Ajanović et al. (2023) consider the problem of agile automated driving on a slippery surface and propose a novel A* search-based task and motion planning approach to determine when to enter and exit drifting manoeuvres when driving around bends on an arbitrary road.

Yue et al. (2022) propose a novel deep learning-based monocular self-supervised depth estimation method for dynamic scenes that eliminates the negative impact of moving objects in the image sequence when calculating the self-supervised loss. Their approach, which has applications in autonomous driving and virtual reality, achieves better performance than existing state-of-the-art methods.

Pérez-Dattari et al. (2022) introduce a motion planning framework for autonomous driving, consisting of a data-driven policy that uses visual inputs and human feedback to generate socially compliant driving behaviours, and a local trajectory optimisation method that executes these behaviours. They employ Interactive Imitation Learning to jointly train the policy and Model Predictive Controller based local planner to ensure safe and human-like driving behaviours.

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2. Intelligent MPC

Li et al. (2022) propose a learning-based MPC scheme incorporating a Gaussian process regression residual model and differential dynamic programming, which they employ to produce an online learning gait generator for biped locomotion.

Cai et al. (2023) formulate energy management in a residential microgrid with prosumers as a cooperative coalition game where the objective is to optimise the benefit to residential prosumers. An MPC-based RL approach incorporating the Shapely value is proposed as a control method to achieve fair distribution of the profits between residents while reducing the long-term economic costs of operating the microgrid.

Floriano et al. (2022) develop a neural network-based MPC solution for achieving consensus in discrete-time nonlinear multi-agent systems. Their approach reduces the effects of communication deficiencies by approximating and minimising the model predictive control cost function in real-time.

Schwedersky and Flesch (2022) introduce a practical nonlinear MPC implementation in which a prediction model consisting of a base prediction generated by a nonlinear LSTM model augmented by an incremental prediction obtained using a linearised version of the LSTM model is used to obtain an optimal control formulation that can be solved using quadratic programming. Their approach includes an iterative update procedure that yields improved closed-loop performance at an affordable level of computational cost for a simulated nonlinear neutralisation reactor, which they use as a case study.

Kordabad and Gros (2022) develop a parameterised tracking MPC-based approach incorporating an additional parameterised storage function that approximates the optimal action-value function of an Economic Nonlinear Model Predictive Control scheme and employ a reinforcement learning based Q-learning approach for parameter optimisation. They show that with optimal parameters, the resulting parameterised storage function satisfies the dissipativity conditions for closed-loop stability for both discounted and undiscounted formulations.

3. Machine learning and reinforcement learning enhanced control

Yu et al. (2023) propose an inverse-free and model-free control scheme based on gradient neural dynamics, which avoids the calculation of pseudo-inverse, to achieve the tracking control of redundant robot manipulators without knowing their kinematic models.

Rego and de Araújo (2022) present a Lyapunov-based continuous-time nonlinear control law determined from a deep neural network for the control of nonlinear systems, demonstrating the efficiency of their approach using a numerical example and experimental simulations for a rotational inverted pendulum.

Conchas et al. (2023) develop a recurrent high-order neural network model of a grid-connected doubly fed induction generator wind turbine. The model, which is trained using an extended Kalman filter approach, is combined with a modified discrete-time sliding mode controller to compensate for sensor faults in order to obtain a fault-tolerant control scheme.

Dixit and ElSheikh (2022) explore the problem of robust optimal control for subsurface reservoir management, a partially observable system with high levels of parameter uncertainty. Employing a model-free reinforcement learning (RL) framework to solve the associated stochastic optimal control problem, they demonstrate the efficiency of proximal policy optimisation and advantage actor–critic RL algorithms for learning robust optimal control policies.

Sierra-Garcia et al. (2022) present a hybrid RL-based control strategy for wind turbine pitch control that combines a RL-based controller with a proportional–integral–derivative (PID) regulator, and a learning observer that oversees the learning process by adjusting the exploration rate and the exploration window in order to reduce oscillations and improve convergence during training.

4. Anomaly detection, fault diagnosis and fault mitigation

Mazzoleni et al. (2022) present a fuzzy logic-based fault diagnosis and condition monitoring methodology that combines anomaly detection algorithms, envelope analysis of vibration data, and additional qualitative information on machine functioning that is targeted at industrial plants where the available data is generally unlabelled. They demonstrate the utility of their methodology for mechanical parts monitoring in a steel making plant.

Cordoni et al. (2022) propose a multi-modal unsupervised deep learning based algorithm for fault detection in commercial refrigerators and apply it to real data from an industrial production line. Their system includes features extracted from thermal images using a deep CNN, and a deep auto-encoder that combines these features with refrigerator power, current and temperature measurements and enables detection of signal anomalies corresponding to faults in the refrigerators.

Mersha and Ma (2022) propose a methodology for airplane angle of attack sensor fault detection, isolation and accommodation that uses a virtual sensor together with two physical sensors to overcome simultaneous failure limitations of existing 3 physical sensor approaches. The virtual sensor is obtained by modelling the aircraft flight dynamics using a recurrent neural network.

Jin et al. (2022) describe an approach for early diagnosis of developing faults in train axle box bearings using an optimised Variational Mode Decomposition for feature extraction and an optimised Deep Belief Network for pattern recognition and fault diagnosis. Both optimisations are performed with an improved implementation of Grey Wolf optimisation algorithm which is designed to address local minima issues that exist with the standard algorithm.

Carletti et al. (2023) propose effective yet computationally inexpensive methods for determining feature importance scores at both global and local levels for Isolation Forest models to enhance their interpretability, and then define a procedure for performing unsupervised feature selection for Anomaly Detection problems that addresses the challenge of feature importance evaluation in unsupervised anomaly detection.

5. Advances in intelligent optimisation

Shan et al. (2022) introduce an improved parallel compact firefly algorithm implementation suitable for limited memory applications and demonstrate its effectiveness on various benchmark optimisation problems and a variable pitch wind turbine PID controller parameter tuning case study.

Chauhan and Vashishtha (2023) develop hybrid meta-heuristic optimisation algorithms based on series and parallel combinations of a genetic algorithm and the slime mould algorithm. Their superiority to existing meta-heuristic algorithms is demonstrated through extensive comparison studies on a range of benchmark optimisation problems.

Koc et al. (2022) explore the use of meta-heuristic algorithms for solving an NP hard land readjustment problem. They introduce customised spatial-based crossover and mutation operators for their problem and investigate several modifications of the Tree-Seed Algorithm. Experimental comparisons with established meta-heuristic methods highlight a double tournament variant of the Tree-Seed algorithm as the most effective approach, outperforming the other algorithms considered in terms of performance and time.

Gregurić et al. (2022) investigate the application of deep reinforcement learning to the control of spatially dynamic speed limit zones on motorways in order to maximise traffic throughput. They employ a bespoke deep neural network model to learn the complex spatio-temporal traffic dynamics and a Deep Deterministic Policy Gradient based RL strategy to generate the optimal speed limit control strategy.

Song et al. (2022) present a deep reinforcement learning based approach to automatically discover new variable ordering heuristics as a means of reducing the complexity of back tracking search algorithms used to solve the Constraint Satisfaction Problem, which is often encountered in automated planning and scheduling tasks.

Szczepanski et al. (2022) employ the artificial bee colony (ABC) algorithm to solve a constrained multi-objective optimisation problem that arises in the scheduling of palletising. They consider the scenario where there are three production lines being serviced by a single robotic arm and show that the proposed approach significantly increases the production rate while satisfying minimum energy and equality of container filling constraints compared to basic and RL based scheduling approaches.

6. AI based approaches in forecasting and prediction

Rubí et al. (2023) investigate the use of machine learning models to predict the spread and behaviour of wildfires and demonstrate that an AdaBoost model is able to predict the areas affected by wildfire with 91% accuracy, outperforming Random Forest, Neural Network, and Support Vector Machine alternatives.

Wang et al. (2022) develop an interpretable data-driven deep learning approach for short-term macroeconomic forecasting based on the N-BEATS neural network, and demonstrate its efficiency compared to traditional Bayesian vector autoregression using macroeconomic data for China.

Arastehfar et al. (2022) present a graph convolutional recurrent neural network architecture for Short-Term Load Forecasting that simultaneously extracts spatial and temporal information from users with similar consumption patterns to improve forecasting accuracy.

Petrović et al. (2023) propose a methodology for determining the optimal number of active toll booths on highways using deep learning, queuing theory and differential evolution. Recurrent neural networks are used to predict the average intensity of vehicle arrivals as an input to a queuing model while differential evolution used to obtain the optimum solution with respect to waiting time and operating costs.

7. Algorithmic contributions

In Xin et al. (2023) an intuitionistic fuzzy three-way approach to transfer learning based on rough almost stochastic dominance is proposed to enhance the transfer of knowledge from source to target domains. They demonstrate the efficiency of their approach on the problem of diagnosing autism from brain image scans.

Varotto et al. (2022) develop a methodology for estimating a stimulation model for visual sensor networks using a combination of Gaussian Mixture Modelling and autoencoder-based dimensionality reduction to achieve a tractable learning problem.

Sala and Armesto (2022) propose a new criterion for adaptive meshing in polyhedral partitions, as used in the interpolation of a value function in Approximate Dynamic Programming (ADP) in optimal control problems. They demonstrate the efficiency of their approach for classical mountain-car and inverted pendulum benchmarks and a 3-DOF robotic arm motion planning task.

Pourasghar et al. (2022) propose novel zonotopic observer designs for a class of uncertain nonlinear systems represented as Takagi–Sugeno fuzzy models, where system uncertainties (considered to be unknown but bounded) are handled via a set-membership framework. They illustrate the utility of their approach for state estimation and fault detection for an autonomous ground vehicle.

Wang et al. (2023) introduce an optimal trajectory-tracking guidance method for Reusable Launch Vehicles based on neural Adaptive Dynamic Programming (ADP). Their approach incorporates an innovative weight iteration for training the critic neural network enabling training computation time to be reduced by 95% compared to traditional gradient descent training.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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We hope that this special issue will inspire readers to explore the possibilities of intelligent control and optimisation, and to contribute to the ongoing efforts to create a more sustainable and equitable future. We would like to thank all the authors and reviewers who have contributed to the special issue. We would also like to express our gratitude to the Editor-in-Chief Prof. Patrick Siarry, the Past Editor-in-chief Ajith Abraham and the Elsevier editorial team. Without their support this special issue would not have been successful.

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