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Editorial

New Trends in the Control of Robots and Mechatronic Systems

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1. Introduction

In recent years, research into the control of robotic and mechatronic systems has led to a wide variety of advanced paradigms and techniques, which have been extensively analysed and discussed in the scientific literature. Some examples of relevant approaches and methods on which researchers are focussing their efforts are fuzzy control [1,2], neural networks [3,4], sliding mode control [5], fractional-order and distributed-order control [6–8], reinforcement learning [9,10], genetic algorithms and evolutionary computation [11,12]. Frequently, on the basis of the specific application requirements, these techniques are used in combination, increasing the level of complexity of the control strategy [13].

On the other hand, a large gap still exists between the scientific state-of-the-art methods and their applications in industry, in which only a limited subset of the research findings has been applied; industry attention is more focussed on man–machine interfaces, connectivity, safety, reliability, costs and other more practical aspects.

This Special Issue is focussed on the new trends in the control of robotic and mechatronic systems, considering in particular applications in which innovative approaches to control bring significant improvements in the system performance, for example, in terms of accuracy [14], readiness, adaptability to different operative conditions and energy efficiency, without increasing the control complexity too much from the end-user point of view or decreasing stability and robustness. In other words, the main intent is to promote the practical feasibility and usefulness of some cutting-edge techniques which can be readily applied in industry.

2. Special Issue Topics

This Special Issue has received several submissions, out of which 13 contributions passed the review process and have been published.

Papers [15,16] deal with two topics that are strictly related: reinforcement learning (RL) and the Markov decision process (MDP). In [15], RL is used to study the autonomous learning mechanism to solve complicated human tasks. The tuning task of cavity filters is considered, which is a common task in the communication industry. In [16], a time-optimal path planning method for autonomous underwater vehicles (AUVs) is proposed based on an MDP algorithm. Its performance is examined under different oceanic conditions, revealing its advantages compared to the A* algorithm, a traditional path planning method. The simulations demonstrate the robustness of the approach even in the case of complex ocean currents.

Additionally, paper [17] deals with AUV path planning in the presence of current disturbances. In this case, the specific application is docking. In this work, a nonlinear model of the vehicle is modelled in a linear parameter varying (LPV) form. Then, the LPV model is used for a model predictive control (MPC) design for computing the set of forces and moments driving the vehicle. The LPV–MPC control action is mapped into the reference signals for the actuators by using a thrust allocation (TA) algorithm. The simulation results show that AUVs can be effectively controlled in a wide range of scenarios.

Moving from water to air, paper [18] discusses the application of distributed control of a fixed-wing unmanned aerial vehicle (UAV) for coordinated tracking under model

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uncertainty and disturbances. Based on the gaussian process regression, a data-driven model is established. Then, a learning-based consensus protocol for multi-UAVs is designed. The stability of the system is proven via a Lyapunov function, and the effectiveness of the proposed method is shown by numerical simulations.

Additionally, the control of ground vehicles is discussed in this Special Issue in [19,20]. In [19], a stair detection and characterization pipeline is presented. The pipeline is tested on a differential drive robot using the ROS middleware. By exploiting this pipeline, a fuzzy controller has been implemented to align the robot autonomously with the staircase. This algorithm can be applied to different robots running the ROS middleware, thus increasing autonomy and allowing the operator to focus on the primary task. Paper [20] discusses the design and simulation of a dynamically stable, self-balancing electric monowheel. A reference model-based adaptive control structure is proposed. A linear quadratic regulator (LQR) and a linear quadratic gaussian (LQG) controller are implemented on the state-space model of the system and compared. Finally, a reference model-assisted adaptive control structure is established to compensate for sudden system parameter changes such as rider mass.

Papers [21–24] deal with motion control for industrial applications, both for single axes [21,22] and for multi-DOF manipulators [23,24]. Paper [21] proposes an analytic solution for state-constrained optimal tracking control problems for continuous-time linear time-invariant (CT-LTI) systems based on model-based prediction, quadratic penalty function, and a variational approach. The simulation results for a DC motor servo system are compared with the results of the direct multi-shooting method and of the implicit model predictive control. In [22], the $PII^{1/2}DD^{1/2}$ control scheme is discussed, in which the half-integral and the half-derivative components are added to the classical PID. The frequency domain responses of the PID, $PI^{\lambda}D^{\mu}$, and $PII^{1/2}DD^{1/2}$ controllers are compared, then the stability features of the $PII^{1/2}DD^{1/2}$ controller are outlined. A Bode plot-based tuning method for the $PII^{1/2}DD^{1/2}$ controller is proposed and then applied to the position control of a mechatronic axis, both in simulation and experimentally. The results show that the use of the proposed scheme results in a remarkable reduction in the position error with respect to the PID, with similar control effort and maximum torque.

As in [22], papers [23,24] also discuss fractional-order (FO) controllers. The work in [23] focusses on the use of FO controllers for a two-DOF flexible manipulator, and undertakes simulations with noise and square wave input. Results show that the FO controllers fit better with the system properties than integer-order controllers. Paper [24] shows an example of a combination of different control techniques; it proposes a fast FO terminal sliding mode control (FFOTSMC) for a seven-degree-of-freedom manipulator with tracking control. The new controller applies the FO derivative on both the sliding surface design and the sliding control/reaching law. Stability analysis is analysed using Lyapunov functions for FO systems. The controller performance is evaluated by simulation on a single-input single-output system model in MATLAB Simulink, and by experiments on a robot manipulator.

The topics of papers [25–27] are miscellaneous. Paper [25] proposes a novel analysis and design methodology of miniaturized inductive sensors with a large measuring range and nanoscale resolution. Firstly, an accurate leakage inductance model is established. Secondly, a design rule for the armature size is proposed by considering the fringing effect. Then, the error terms introduced by the measurement circuit of differential inductive sensors are analysed, and corresponding error suppression methods are described.

Paper [26] deals with clinical analyses to evaluate balance control performance, and in particular with experimental protocols and devices that can provide reliable information about the ability of a subject to maintain balance. A test bench, supported by model simulations, was developed to test the proposed perturbation device. The performance of the control logic has been optimized by iterative tuning of the controller parameters, and the resulting behaviour of the automatic perturbator is discussed.

Paper [27] illustrates a method to prove the stability of a generic neural network a posteriori and its application in a state-of-the-art recurrent neural network architecture. The proposed method relies on identifying the poles associated with the designed network starting from the input/output data. Providing a framework to guarantee the stability of any neural network architecture, combined with their generalizability and applicability in different fields, can significantly expand their use in dynamic system modelling and control.

Overall, the accepted papers illustrate a wide variety of alternative approaches and methods for improving the performance of mechatronic and robotic systems, with possible additional applications in related emerging fields, such as biomechanics. The Guest Editor expects and hopes that the articles published in this Special Issue will contribute significantly to forming the backbone of systematic developments in this research field.

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