fractal and fractional

Editorial

Closing Editorial for Applications of Fractional-Order Systems in Automatic Control

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Fractional-order systems have been applied in very diverse areas of science and engineering. The fractional-order calculus is a generalization of the integration and differentiation operators to non-integer order. The fractional-order provides additional flexibility and adjustments to the operation specifications. In automatic control, fractional systems allow forms of response that are impossible to achieve with classical control, e.g., improvement in noise measurement attenuation without unnecessarily deteriorating the disturbance rejection properties and, consequently, the time response of the closed-loop system.

The focus of this Special Issue is to show the advances in research on topics related to the theory, design, implementation, and application of fractional-order systems in automatic control. The works presented in this technical publication are those that have appeared in the *Fractal and Fractional* journal in a Special Issue of the same name, which included the thirteen individually published papers plus an Editorial signed by the editors of this reprint.

The papers of this reprint have been categorized into the following two main sections:

- Control Theory: Fractional-order Control Design and Stability Analysis;
- Control Engineering.

The later section, Control Engineering, has been divided into the following:

- ○ Applications of Fractional-Order Control for Automotive Control Systems;
- ○ Applications of Fractional-Order Control for Unmanned Vehicles;
- ○ Applications of Fractional-Order Control for Robotics;
- ○ Applications of Fractional-Order Control for Electric Power/Power Electronics.

The section on Control Theory: Fractional-Order Control Design and Stability Analysis consists of three papers. In the first work of this section entitled "Discrete-Time Design of Fractional Delay-Based Repetitive Controller with Sliding Mode Approach for Uncertain Linear Systems with Multiple Periodic Signals", the authors introduce a discrete-time design of a fractional internal model-based repetitive controller with a sliding mode approach presented for uncertain linear systems subject to repetitive trajectory and periodic disturbance. The proposed algorithm aims to enhance tracking accuracy, transient response, and robustness against parametric variations beyond what is offered by conventional repetitive controllers. Comparative simulation studies demonstrate the superior performance of the proposed controller. In the reference, namely, "Analysis of Error-Based Switched Fractional-Order Adaptive Systems: An Error Model Approach," the authors address a general analytical framework that allows proving the boundedness of the solutions and convergence of the estimation/tracking error with only particular analyses for specific schemes being accessible, presenting the analysis of four error models that can appear in the field of adaptive systems when these adaptive laws are chosen.

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The boundedness of the solutions is proved for all cases, together with the convergence to zero of the estimation/tracking error. A numerical example is included to show the possible advantages of using switched adaptive laws in a model reference adaptive control application.

The work “Fractional-Order Control Method Based on Twin-Delayed Deep Deterministic Policy Gradient Algorithm” which is the third selected work of this section proposes a fractional-order control method based on the twin-delayed deep deterministic policy gradient (TD3) algorithm in reinforcement learning. A fractional-order disturbance observer is designed to estimate the disturbances, and the radial basis function network is selected to approximate system uncertainties. Then, a fractional-order sliding-mode controller is constructed to control the system, and the parameters of the controller are tuned using the TD3 algorithm, which can optimize the control effect. The results show that the fractional-order control method based on the TD3 algorithm can not only improve the closed-loop system performance under different operating conditions but also enhance the signal tracking capability.

The section on Control Engineering, Applications of Fractional-Order Control for Automotive Control Systems, consists of a manuscript “Vibration Suppression of the Vehicle Mechatronic ISD Suspension Using the Fractional-Order Biquadratic Electrical Network,” with a positive real synthesis design method of vehicle mechatronic Inerter-Spring-Damper (ISD) suspension based on the fractional-order biquadratic transfer function is proposed. In this work, the positive real condition of the fractional-order biquadratic transfer function is given. Then, a quarter dynamic model of the vehicle mechatronic ISD suspension is established, and the parameters of the fractional-order biquadratic transfer function and vehicle suspension are obtained by a genetic algorithm. The main objective of the work is to break the constriction of the integer-order transfer function in vehicle ISD suspension design.

The section on Control Engineering, Applications of Fractional-Order Control for Unmanned Vehicles consists of two papers. In the paper “Fractional-Order Controller for the Course Tracking of Underactuated Surface Vessels Based on Dynamic Neural Fuzzy Model,” the authors proposes a control algorithm based on the dynamic neural fuzzy model (DNFM). The DNFM simultaneously adjusts the structure and parameters during learning and fully approximates the inverse dynamics of ships. Aiming at the uncertainty problem caused by the time-varying modeling parameters associated with ship speed in the course tracking control of underactuated surface vessels (USVs). Simulation experiments were conducted, respectively, for course tracking, course tracking under wind and wave interferences, and comparison with five different controllers. This proposed controller can overcome the influence of the uncertainty of modeling parameters, tracking the desired course quickly and effectively. The second paper of this section is titled “Hover Flight Improvement of a Quadrotor Unmanned Aerial Vehicle Using PID Controllers with an Integral Effect Based on the Riemann–Liouville Fractional-Order Operator: A Deterministic Approach,” which proposes a set of PID controllers with an integral effect based on the Riemann–Liouville fractional-order approach to improve the hovering flight of a quadrotor UAV. This research introduces a set of fractional-order PID controllers for UAV hover stability, which offer better adaptability to non-linear dynamics and robustness than traditional PID controllers. The numerical simulation results show the effectiveness of the proposed Fractional Integral Action PID Controller in the control of UAV hovering flight, while comparative analyses against a classical controller emphasize the benefits of the fractional-order approach in terms of control accuracy.

The section, Control Engineering, Applications of Fractional-Order Control for Robotics has three papers. In the first work of this section one finds the work “Robust

Fractional-Order PI/PD Controllers for a Cascade Control Structure of Servo Systems," where a cascade control structure is suggested to control servo systems that normally include a servo motor in coupling with two kinds of mechanism elements, a translational or rotational movement. These kinds of systems have high demands for performance in terms of the fastest response and no overshoot/oscillation to a ramp function input. The fractional-order proportional integral (FOPI) and proportional derivative (FOPD) controllers are addressed to deal with those control problems due to their flexibility in tuning rules and robustness. Simulation studies are considered for two kinds of plants that prove the effectiveness of the proposed method, with good tracking of the ramp function input under the effects of the disturbances. The next work, namely, "A Fractional-Order ADRC Architecture for a PMSM Position Servo System with Improved Disturbance Rejection," proposes an active disturbance rejection control (ADRC) architecture for a permanent magnet synchronous motor (PMSM) position servo system. The presented method achieved enhanced tracking and disturbance rejection performance with a limited observer bandwidth. The model-aided extended state observer (MESO)-based ADRC was designed for the current, speed, and position loops of the PMSM position servo system. The results demonstrate not only that the proposed method achieved superior tracking performance but also that the position error of the proposed strategy decreases to 2.25% when the constant disturbance was input, significantly improving the disturbance rejection performance. The third work of the section Control Engineering, Applications of fractional-order control for Robotic is "Fractional Control of a Class of Underdamped Fractional Systems with Time Delay—Application to a Teleoperated Robot with a Flexible Link," where the authors addresses the robust control of processes modeled by a fractional-order time delay transfer function. A new method for tuning fractional-order PI and PD controllers is developed. The stability is assessed based on the frequency domain tuning of the regulators to control such delayed fractional-order underdamped processes. In order to analyze the closed-loop stability and robustness, the new concept of Robust High-Frequency Condition is introduced. The analysis based on that demonstrates that each controller has a different region of feasible frequency specifications, and, in all cases, they depend on their fractional integral or derivative actions. Finally, an application example, the position control of a teleoperated manipulator with a flexible link, is presented.

Finally, the section in Control Engineering, Applications of Fractional-Order Control for Electric Power/Power Electronics, is composed of four papers. The first work of this section is "Fractional-Order Phase Lead Compensation Multirate Repetitive Control for Grid-Tied Inverters". In this work, a fractional-order phase lead proportional-integral multi-resonant multi-rate repetitive control (FPL-PIMR-MRC) is proposed for grid-tied inverters. The proposed method can provide a suitable fractional phase lead step to achieve a wide stability region, minor tracking errors, and low hardware costs. The IIR fractional-order lead filter design, stability analysis, and step-by-step parameter tuning of the FPL-PIMR-MRC system are derived in detail. Finally, the simulation performed confirms the feasibility and effectiveness of the proposed scheme. The next work is titled "Optimal Fractional-Order Controller for the Voltage Stability of a DC Microgrid Feeding an Electric Vehicle Charging Station" suggests a fractional-order proportional integral (FOPI) controller to improve the performance and energy management of a standalone electric vehicle charging stations (EVCSs) microgrid. The microgrid is supplied mainly by photovoltaic (PV) energy and utilizes a battery as an energy storage system (ESS). The FOPI's settings are best created utilizing the grey wolf optimization (GWO) method to attain the highest performance possible. The results demonstrate that the suggested FOPI controller significantly improves the transient responsiveness of the EVCSs performance compared to the standard PI controller. The results support the suggested FOPI control's robustness to parameter mismatches. The third work, namely, "Automatic Voltage Regulator Betterment Based on a New Fuzzy FOPI+FOPD Tuned by TLBO," presents a novel Fuzzy Logic Controller (FLC) framework aimed at enhancing the performance and stability of Automatic Voltage Regulators (AVRs). The proposed system combines fuzzy control theory with the Fractional-Order Proportional Integral Derivative (FOPID) technique and employs cascading control theory to significantly improve reliability and robustness. The methodology is validated through comparative analyses with controllers reported in prior studies, highlighting substantial improvements in performance metrics. Key findings demonstrate significant reductions in peak overshoot, peak undershoot, and settling time, emphasizing the proposed controller's effectiveness. The last work presented in the section is "Applying a Gain Scheduled Fractional Order Proportional Integral and Derivative Controller to a Quadratic Buck Converter," which is also the last paper of the editon. This work present a fractional-order proportional integral and derivative controller with adaptation characteristics in the control parameters depending on the required output, gain scheduling fractional-order PID (GS-FO-PID). In this work a fractional-order PID is applied to the voltage control of a DC–DC buck quadratic converter (QBC). The performance of the GS-FO-PID is compared with the one from a classic PID. The GS-FO-PID presents better performance when the reference voltage is changed and also with load changes.

Thus, this Special Issue, which is the subject of our Editorial, brings together some novel ideas on the application of fractional calculus in automatic control systems; it is a significant and relevant volume for our field of study and will be appreciated as a useful reference within the specialized literature.

Conflicts of Interest: The authors declare no conflicts of interest.

List of Contributions:

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