Modeling, Analysis, and Advanced Control in Motion Control Systems—Part I

PRECISION, agility, robustness, efficiency, and intelligence are now becoming the design indexes for modern motion control systems. High control performance, intelligent functions, or efficiency improvements advance the level of motion control products or systems and bring a lot of benefits for companies. The difficulties for the control research academics and practicing engineers lie in various factors, such as nonlinearities, friction, complex internal dynamics, time-varying parameters in the system dynamics, external disturbances in the working environment, and complex work tasks. These make the control design a very challenging work. To employ advanced control algorithms and schemes, time-/frequency-domain modeling, system identification, observation for unmeasured states, estimation for pivotal parameters, and the corresponding analyses are often necessary.

The main objectives of this "Special Section on Modeling, Analysis, and Advanced Control in Motion Control Systems—Part I" of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS are to build a platform for research academics and practicing engineers of the industrial electronics and industrial informatics communities to present their most recent findings related to digital control systems in motion control systems.

This part of the Special Section consists of nine papers; other papers will be published later. From the application point of view, the selected papers cover different motion control systems, such as general mechanical systems [1], electrohydraulic actuators [2], smart-material-based actuators [3], flexible joint robots [4], multiple mobile robots [5], magnetically levitated planar motors [6], road vehicles [7], helicopters [8], and unmanned turret systems [9].

Topics of interest of this Special Section include various advanced modeling, analysis, and control techniques for motion control systems with simulation and/or experimental verifications, particularly, time-domain [3]–[9] and frequency-domain [1]–[2] modeling, estimation or identification for uncertainty/disturbance or parameter of motion control systems [6]–[9], model information-based optimization for motion control systems [3], [5], adaptive/intelligent control design for motion control systems [3], [5]–[7], etc.

Reference [1] presents a study of the real-time nonparametric frequency-domain identification and modeling of mechanical systems in electric drives. This problem is important to the diagnostics and condition monitoring as well as adaptive control in various application fields. A kind of sliding discrete Fourier transform-based method is developed for frequency-domain-based online monitoring and parameter estimation of a mechanical system with varying dynamics at a selected set of frequencies. The effectiveness is shown by experimental verifications on a tooth-belt drive with a movable mass.

Reference [2] discusses the problem of improving fuel economy and reducing emissions by advanced control design. Robust time-varying reference tracking control and its application to the electrohydraulic camless engine valve actuator are addressed. The control design is challenging due to the nonlinearity of the electrohydraulic actuator and the time-varying reference valve motion depending on the time-varying engine speed. A nonlinear frequency-domain model of the electrohydraulic actuator is built. A block-oriented nonlinear model, i.e., Wiener model, is employed. Then, a time-varying motion controller with the time-varying internal model is developed. The effectiveness of the proposed method is demonstrated with the prototype of the electrohydraulic camless engine valve actuator.

One of the difficulties in control of a smart-material-based actuator system is the hysteresis phenomena/nonlinearities. Reference [3] considers the design of a control algorithm for a hysteretic system/device with only output signal available. This is particularly interesting for some systems like the piezoelectric positioning system where the velocity and acceleration are usually not convenient to measure. A neural-network-based robust adaptive output-feedback motion controller for a class of hysteretic nonlinear systems is proposed. First, a high-gain state observer is designed to estimate the states. Then, radial basis function neural networks are employed as an approximator for the unknown nonlinearity. Later, a dynamic surface inverse control with adaptive laws of unknown parameters is developed. Experiments on the piezoelectric positioning stage are conducted to show the performance advantages.

Flexible joint robots may have torsional elasticities with hysteresis. The nonlinear torsion can lead to the control errors when reference tracking and positioning the robotic links. Reference [4] compares two types of compensation methods for the nonlinear joint torsion in elastic robotic joints. The first method can be regarded as a kind of feedforward control law for the general case of nonlinear joint stiffness with hysteresis. The second method is based on the so-called virtual torsion sensor, which estimates the reactive joint torque based on the available motor torque and velocity and predicts the relative joint torsion based on the inverse hysteresis map. An extensive example of the standard two-link planar manipulator under gravity is given to compare the reference tracking performance under these two compensations methods. Finally, some conclusions and suggestions are made.

Reference [5] discusses the leader–follower formation control problem for multiple mobile robots. Considering the input constraints and collision avoidance requirement, a nonlinear model predictive control scheme is developed for two-robot formations that include the leader–follower model and avoidance model.

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The novelty here lies in that the constrained quadratic programming is solved by introducing the primal-dual neural network with parallel capability. Experimental results on the application of the proposed formation control approach to several mobile robots are demonstrated to verify the effectiveness.

The magnetically levitated planar motor is a kind of new-generation motion device. Considering the repetitive motion tasks in many application cases, an iterative learning control (ILC) method is known as a very effective solution. However, conventional ILC methods are not robust against parameter variations and disturbances. To this end, [6] proposes a learning adaptive robust control (LARC) scheme for a magnetically levitated planar motor, where the LARC control scheme is an intelligent integration of adaptive robust control and ILC in a serial structure. The performance superiority of the proposed method is well demonstrated by detailed experimental comparisons, which are carried out on the magnetically levitated planar motor to track sinusoidal, point-to-point, and planar circular motions in different cases.

Steer-by-wire (SBW) vehicle systems have been developed to replace the current electric power and hydraulic power-assisted steering systems. Considering parameter uncertainties and varying driving conditions, [7] proposes an adaptive terminal sliding-mode control scheme for an SBW vehicle. The introduction of terminal sliding-mode control design ensures the fast finite-time convergence of the closed-loop error dynamics in the presence of uncertain parameters and disturbances. Experimental results from an SBW vehicle are provided to verify the superior performance of the proposed control method in terms of transient and steady-state responses as well as robustness in comparison with other control strategies.

The 3-DOF helicopter is a kind of featured aerospace platform that recreates a real tandem helicopter. Reference [8] aims at improving the robustness of attitude control for a helicopter against uncertainties and disturbances. Since only angular position is measurable, a continuous differentiator is introduced to estimate the states. An adaptive supertwisting sliding-mode controller is developed to improve the dynamical behavior of the closed-loop attitude system. Experimental verifications for regulation and tracking control cases are given to illustrate the effectiveness of the proposed control scheme.

The unmanned turret system is a kind of hot developing issue of armor weapon systems. Considering simultaneously the outer disturbances, inner uncertainties, and the coupling between the horizontal and vertical components, a fast nonsingular terminal sliding-mode control strategy is developed with an extended-state observer (ESO) in [9]. Here, the ESO is introduced to estimate the unknown coupling item, and the estimate value is treated as a compensation to unknown uncertainties and disturbances, which helps to reduce the chattering caused by high switching gain. Simulation results are given to show the effectiveness of the proposed control strategy.

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