An Introduction to the Special Issue on Time Delay Systems: Modelling, Identification, Stability, Control and Applications

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The special Issue "Time Delay Systems: Modelling, Identification, Stability, Control and Applications" intents to collect high-erudite papers aiming theoretical and/or practical matters dealing with time delay systems.

In feedback control systems, delay as a generic part of many processes is the phenomenon which unambiguously deteriorates the quality of a control performance. Modern control theory has been dealing with this problem since its nascence – the well known Smith predictor has been known for longer than five decades. Systems with delays in technological and other processes are usually assumed to contain delay elements in input-output relations only, which results in shifted arguments on the right-hand side of differential equations. All the system dynamics is hence traditionally modelled by point accumulations in the form of a set of ordinary differential equations. However, this conception is a rather restrictive in effort to fit the real plant dynamics since inner feedbacks can be of time-distributed or delayed nature. Time delay (hereditary, anisochronic) models, contrariwise, offer a more universal dynamics description applying both derivatives and delay elements on the left-hand side of a differential equation, either in a lumped or distributed form.

Modelling, identification, stability analysis, stabilization, control, etc. of time delay systems are challenging and fascinating tasks in modern systems and control theory as well as in academic and industrial applications. Many related problems are unsolved and many questions remain unanswered.

The aim of this special issue is to highlight greatly significant recent developments on the topics of time delay systems, their estimation, modelling and identification, stability analysis, various (algebraic, adaptive and predictive) control strategies, relay-based autotuning and interesting academic and real-life applications. The papers included in the special issue are ordered from the most theoretical one to more directly applicable ones.

The state estimation or filtering problem is of great importance in both theory and application, and in the last decades, this problem has gotten extensive concern and many solution schemes have been proposed and successfully put into action. Among them, Kalman filtering, which minimizes the variance of the estimation error, is the most famous one. Observer design for linear time delay systems is the matter of the first paper of Mohammad Ali Pakzad, entitled "Kalman Filter Design for Time Delay Systems". An easy way to compute least square estimation error of an observer for time delay systems is derived, where the time delay terms exist in the state and output of the system. Based on the least square estimation error an optimization algorithm to compute a Kalman filter for time delay systems is proposed. By employing the finite characterization of a Lyapunov functional equation, the existence of sufficient conditions for obtaining the right solution and guaranteeing the proper convergence rate of the estimation error is evaluated. It is shown that this finite characterization can be calculated by means of a matrix exponential function. The desirable performance of the proposed observer is demonstrated through the simulation of several numerical examples.

Fractional differential equations have gained considerable significance and most fractional systems may contain a delay term. The authors Mohammad Ali Pakzad and Sara Pakzad propose an exact method for the BIBO stability analysis of a large class of fractional order delay systems. In their paper entitled "Stability Map of Fractional Order Time-Delay Systems", the stability robustness for linear time invariant fractional order systems with time delay against delay uncertainties is considered. The complexity arises due to the exponential type transcendental terms and fractional order in their characteristic equation. It is shown that this procedure numerically reveals all possible stability regions exclusively in the space of the delay. Using the approach presented in this study, all the locations where roots cross the imaginary axis are found. Finally, the concept of stability as a function of time delay is described for a general class of linear fractional order systems with multiple commensurate delays.

A revision and extension of the ring of retarded quasipolynomial meromorphic functions for description and control of time-delay systems is the aim of the paper "A Ring for Description and Control of Time-Delay Systems" by Libor Pekař. The new definition extends the usability to neutral systems and to those with distributed delays. First, basic algebraic notions useful for this paper are introduced. A concise overview of algebraic methods for time delay systems follows. The original and the revised definitions of the ring together with some its properties finish the contribution. Many illustrative examples that explain introduced terms and findings can be found throughout the paper.

Algebraic design of controllers for time delay systems having integrative or unstable properties is the topic of the paper entitled "Control of Unstable and Integrating Time Delay Systems Using Time Delay Approximations" by Petr Dostál, Vladimír Bobál and Zdeněk Babík. The proposed method is based on two methods of time delay approximations. The control system with two feedback controllers obtained via the polynomial approach and the linear quadratic technique is considered. Resulting continuous-time controllers ensure asymptotic tracking of step references as well as step disturbances attenuation.

The majority of processes in the industrial practice have stochastic characteristics and eventually they exhibit nonlinear behaviour. Traditional controllers with fixed parameters are often unsuitable for such processes because parameters of the process change. One possible alternative for improving the quality of control of such processes is application of adaptive control systems. The authors Vladimír Bobál, Petr Chalupa, Marek Kubalčík and Petr Dostál designed a toolbox in the MATLAB/SIMULINK environment for identification and self-tuning control of time delay systems in the paper entitled "Identification and Self-tuning Control of Time-delay Systems". The control algorithms are based on modifications of the Smith predictor. The designed algorithms that are included in the toolbox are suitable not only for simulation purposes but also for implementation in real time conditions. Verification of the designed toolbox is demonstrated on a self-tuning control of a laboratory heat exchanger in simulation conditions.

A rather similar problem is the issue of the next paper entitled "Predictive Control of Higher Order Systems Approximated by Lower Order Time-Delay Models". There often occur higher order processes in technical practice, the designed optimal controllers for which lead to complicated control algorithms. One of possibilities of solving the problem is their approximation a by lower-order model with dead time. The contribution of Marek Kubalčík and Vladimír Bobál is focused on a choice of a suitable experimental identification method and excitation input signals for an estimation of process model parameters with time-delay. One of the possible approaches to control of time-delay processes is the application of model-based predictive control methods. Design of an algorithm for predictive control of high-order processes which are approximated by second-order model of the process with time-delay then follows in the paper.

The last paper in the special issue: "Autotuning Principles for Time-delay Systems" by Roman Prokop, Jiří Korbel and Radek Matušů focuses single input–output principles for tuning of continuous-time controllers used in autotuning schemes. Autotuners represent a combination of relay feedback identification and some control design method. In this contribution, models with up to three parameters are estimated by means of a single asymmetrical relay experiment. Then a stable low order transfer function with a time delay term is identified by a relay experiment. Controller parameters are analytically derived from general solutions of Diophantine equations in the ring of proper and stable rational functions. This approach covers a generalization of PID controllers and enables to define a scalar positive parameter for further tuning of the control performance. The analytical simple rule is derived for aperiodic control response. Simulations are performed in the Matlab environment and a toolbox for automatic design was developed.

This special issue is created by mathematicians, system- and control-engineers and scientists who study various problems in analysis and control of dynamical systems including the very rich family of those with time delays. We are looking forward to hearing reactions and comments from you, the reader, as you engage in your design struggles and successes as well. We hope this special issue can support the designing of new communities and facilitating new groups of learners, engineers and scientists as well. We dare to claim that this issue made a little contribution to a better, feel-good, world.