

## EDITORIAL

### Special issue on time-delay systems

Time-delay often appears in many control systems (such as aircraft, chemical or process control systems) either in the state, the control input, or the measurements. Unlike ordinary differential equations, delay systems are infinite dimensional in nature and time-delay is, in many cases, a source of instability. The stability issue and the performance of control systems with delay are, therefore, both of theoretical and practical importance.

Delay equations were first considered in the literature in the XVIII century (e.g. the works of Bernoulli, Euler or Condorcet). A systematic study of such equations began in the 20's of the XX century by V. Volterra, and in the end of 40's of the same century by A. Myshkis and R. Bellman. Lyapunov's second method for the stability of delay systems was developed at the end of 50's by N. Krasovskii who introduced Lyapunov functionals and by B. Razumikhin who formulated the appropriate Lyapunov functions. Since 1950s, the subject of delay systems or functional differential equations has received a great deal of attention in Mathematics, Biology and Control Engineering.

Over the past decade, much effort has been invested in the analysis and synthesis of *uncertain* systems with time-delay. Based on the Lyapunov theory of stability, various results have been obtained that provide, for example, *finite-dimensional* sufficient conditions for stability and stabilization. Departing from the classical linear finite-dimensional techniques which apply Smith predictor type designs, the new methods simultaneously allow for delays in the state equations and for uncertainties in both the system parameters and the time delays.

During the early stages, delay-independent results were obtained which guarantee stability and prescribed performance levels of the resulting solutions. Recently, delay-dependent results have been derived that considerably reduce the overdesign entailed in the delay-independent solutions.

In the present issue, new results are obtained for various control and identification problems for delay systems. These results are based either on Lyapunov methods or on frequency domain considerations.

The nine papers included in this issue have been written by prominent specialists in the field of Systems and Control who have touched upon a variety of control and stability problems for linear and nonlinear systems with delay.

Lyapunov-based stability methods for different classes of *linear* delay equations, either continuous or discrete time (difference equations), are presented in the first three papers:

- V. Kharitonov and D. Melchor-Aguilar introduce Lyapunov–Krasovskii functionals for functional equations describing additional dynamics, which appear when the model transformation for delay-dependent stability is used. Some basic properties of these functionals are discussed.

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- V. Kolmanovskii and L. Shaikhet develop a method to construct Lyapunov functionals for stochastic difference Volterra equations. The stability regions for systems with unbounded memory are found.
- K. Gu presents an improved discretized Lyapunov functional method for systems with distributed delays. The main idea is the application of Jensen's Inequality and elimination of variables in the ensuing matrix inequalities.

The next three papers focus on some control problems for *linear* systems with delay:

- K. Uchida, K. Ikeda, T. Azuma and A. Kojima consider an output feedback  $H_\infty$  control for systems with delays in both the inputs and outputs. Conditions are found under which the problem is equivalent to a finite dimensional one without delays.
- R. Rabah and M. Malabre consider the row-by-row decoupling problem for delay systems by output-feedback. The solvability of the problem is given in terms of some easily verifiable structural conditions.
- Y. Orlov, L. Belkoura, J.P. Richard and M. Dambrine derive necessary and sufficient conditions for the identification of the systems' parameters and delays. The systems under consideration are governed by functional differential equations with uncertain time-invariant parameters and delays.

An application of the stability analysis of delay systems to bilateral teleoperation with communication delays then follows:

- In the paper by S. Niculescu, D. Taoutaou and R. Lozano, the conditions for stability are derived using a frequency domain approach. Analytical and easily verifiable delay-independent and delay-dependent conditions are presented.

The last two papers deal with *nonlinear* control problems with delays:

- E. Fridman, A. Pila and U. Shaked consider stabilization and  $H_\infty$  control of linear delay systems with saturating actuators. A linear polytopic representation is used. The Lyapunov–Krasovskii method with the descriptor model transformation is applied for stabilization results, while  $H_\infty$  control is treated also by the Lyapunov–Razumikhin approach.
- A. Germany, C. Manes, P. Pepe investigate the issue of the internal stability of nonlinear delay systems controlled by a feedback law that perform exact input–output linearization and delay cancellation. The relationship between the internal state and input dynamics is studied.

Finally, we would like to thank all the contributors to this special issue. Owing to the high quality of the papers contributed, our task was difficult but very rewarding.

*Guest Editors*

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