

## EMILIA FRIDMAN

**Q.** How did your education and early career lead to your initial and continuing interest in the control field?

*Emilia:* My brother Leonid Fridman and I learned from our father (a talented lecturer in mathematics) that there is nothing better than mathematics. So I earned all of my degrees in mathematics, including a Ph.D. in dynamical systems (supervised by Vadim Strygin, who earned his Ph.D. under the supervision of Mark Krasnosleskii). My research interests were center manifold theory and asymptotic methods for time-delay singularly perturbed systems with applications to optimal control problems.

A turning point toward control was moving from Russia to Israel at the end of 1992. My husband (who worked in algebraic geometry) got a position in the School of Mathematics at Tel Aviv University (TAU). I was told that there was no chance to have a position in the same school for a couple. Walking around the campus with our small son, I came to the engineering buildings, where I had heard about Prof. Uri Shaked, who worked in  $H_\infty$  control. I had no idea about  $H_\infty$  control at that time, but Vladimir Gaitsgory forwarded me a paper by Tamer Basar on the  $H_\infty$  control of linear, singularly perturbed systems, in which I found familiar (from classical linear-quadratic Riccati) Riccati equations. So, I wrote a research proposal on asymptotic methods for singularly perturbed  $H_\infty$  control that was of interest to Uri Shaked. That proposal led to a fellowship from the Israeli Ministry of Absorption for a research position at TAU, and since then I have been working on control theory.

**Q.** What are some of your research interests?

*Emilia:* My main research interests are robust control of time-delay systems with applications to, among other things, sampled-data and networked control systems as well as some bio-



Emilia Fridman.

logical systems. I have also resumed my prior analysis of robust control for distributed-parameter systems.

Time delay appears in many control systems. For example, the actuators and sensors used in the feedback loops typically introduce delays. Time delay is, in many cases, a source of instability but, for some systems, the presence of delay can have a stabilizing effect. In the latter case, a delay can be artificially introduced to stabilize the system or to improve its performance.

Most modern control systems are implemented as sampled-data controllers using digital technology. In the time-delay approach to sampled-data control, the closed-loop system is modeled as a continuous-time one with delayed input/output. This framework enables an analysis of the performance of the closed-loop, continuous-time system. This approach became popular for

networked control systems, where the plant and the controller exchange data via a communication network.

Having a background in differential equations with time delays, I was lucky that the time-delay topic became popular in control theory at the end of the 20th century. Working with asymptotic and geometric methods for time-delay systems, I was puzzled by Uri Shaked's questions about an upper bound on the delay that preserves stability or the performance of the system because the upper bound that followed from the asymptotic analysis was close to zero, which was far from its analytical value. This turned me to constructive Lyapunov methods that may lead to much more accurate upper bounds on the delay.

I also would like to mention the EuroDif conference in 1999, which included an impressive talk by Jack Hale on nonrobustness with respect to arbitrarily small delays in some infinite-dimensional systems. I understood that in singularly perturbed systems, arbitrarily small delays that are independent of the singular perturbation parameter may destabilize the system. To justify this qualitative behavior, I used center manifold theory, but to find some constructive and simple quantitative results (efficient upper bounds on delays and the singular perturbation parameter that preserve the stability), I had to use Lyapunov methods. The effects of delays on



Emilia with Jean-Pierre Rischard and Stanislav Vasiliev at the 2008 IFAC World Congress.

singularly perturbed systems led me to a descriptor approach to time-delay systems. The descriptor approach and the new Lyapunov–Krasovkii functionals allowed, for the first time, for the analysis of systems with fast varying delays (without any constraints on the delay derivative). Moreover, the descriptor approach (that brought additional “slack variables” to matrix inequalities and led to advantages in the analysis and design of uncertain systems) has also been applied by many researchers to robust control of systems with and without delay.

I am grateful to Jean-Pierre Richard for his invitations to visit Ecole Centrale de Lille, which led to a fruitful collaboration with him and his group; in 2002, we started to work on sliding-mode control of systems with state delays and on the time-delay approach to sampled-data control. Modeling of continuous-time systems with digital control in the form of continuous-time systems with time-varying delay and the extension of the Lyapunov–Krasovskii method to systems with fast-varying delays and to discontinuous delays have allowed the development of the time-delay approach to sampled-data and to network-based control.

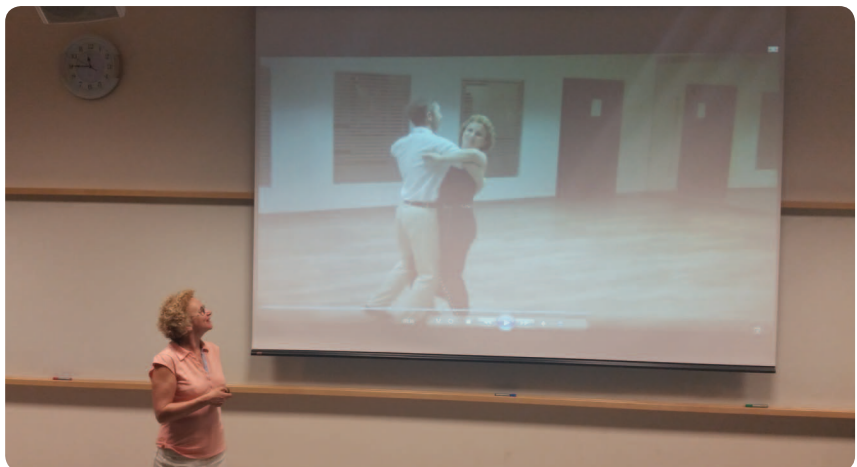
During my French visits, I have also started a collaboration on distributed-parameter systems with Yury Orlov. We suggested the linear-matrix inequality (LMI) approach to distributed-parameter systems that was capable of using nonlinearities and of providing a desired system performance in spite of significant model uncertainties.

As it happened with time-delay systems, I believe that LMIs will provide effective constructive tools for the analysis and control of distributed-parameter systems. Moreover, a good understanding of the qualitative behavior of the system helps to construct efficient quantitative methods.

**Q.** What courses do you teach related to control? Do you have a favorite course? How would you describe your teaching style?



Emilia in Beijing with her former Ph.D. student Kun Liu.



Emilia presenting her lecture, Time-Delay Systems: Stabilizing Delay in Tango, using the dancing clips prepared with her husband.

**In the time-delay course, I illustrate stabilizing and destabilizing effects of delays on dances (dancing is my hobby).**

*Emilia:* I teach an undergraduate course, Introduction to Modern Linear Control, that covers controllability and observability, linear-quadratic regulation, and Kalman filters, and two graduate courses, Optimal Control and Time-Delay Systems. My

favorite course is the recent advanced time-delay course that is still under construction (I am constantly adding new results). In teaching, I am trying to follow the advice of Vadim Strygin and Mark Krasnoselskii to explain new ideas by simple examples, as well as

## Profile of Emilia Fridman

- *Current position:* professor, Tel Aviv University.
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- *IEEE experience highlights:* member, technical committee, Conference on Decision and Control, 2013–2015; associate editor, *Automatica*, 2007–present; associate editor, *SIAM Journal on Control and Optimization*, 2010–present.
- *Notable awards:* Highly Cited Researcher in 2014 by Thomson Reuters.

my father's advice to mention historical facts on the subject, the biographies of the related researchers, and to insert some jokes.

In the time-delay course, I illustrate stabilizing and destabilizing effects of delays on dances (dancing is my hobby). Thus, I illustrate stabilization by using delay with the tango, where, after the pivots, a stop, that is, a delay, is required (this is a

*Emilia:* There are a lot of promising opportunities. Particularly for me and my Mexican brother, there are opportunities to meet each other a few times per year at control conferences or research visits. More seriously, I would like to mention the field of infinite-dimensional (time-delay and PDE) systems. In the past, many control problems for infinite-dimensional systems have been approximated by simpler finite-dimen-

**My favorite course is the recent advanced time-delay course that is still under construction (I am constantly adding new results).**

kind of zero-order hold). Otherwise, the dancers will “fly” by inertia. My husband and I, together with our dance instructor, have prepared special dancing clips illustrating delay effects on stability and performance. We learned that it is not easy to do such clips because a lot of repetitions are needed, and you always have to keep smiling.

**Q.** What are some of the most promising opportunities you see in the control field?

sional models that lead to the control of complicated high-dimensional systems and still cannot guarantee results for the original system. Moreover, the delay effects have been frequently ignored. The development of efficient and simple constructive direct methods for infinite-dimensional systems will attract engineers to implement these methods. I believe that, in the future, infinite-dimensional systems will be more heavily involved in different applications leading to new theoretical problems and elegant solutions.

**Q.** You are the author of the monograph *Introduction to Time-Delay Systems: Analysis and Control*. What topics does this book cover?

*Emilia:* As I say in the introduction to the book, the beginning of the 21st century can be characterized as the time-delay boom, leading to numerous important results. The purpose of this book is two-fold, to familiarize the nonexpert reader with time-delay systems and to provide a systematic treatment of modern ideas and techniques for experts. This book is based on the course Introduction to Time-Delay Systems for graduate students in engineering and applied mathematics that I taught in Tel Aviv University. The book leads the reader from some basic classical results on time-delay systems to recent developments on Lyapunov-based analysis and design with applications to the hot topics of sampled-data and network-based control. The objective is to provide useful tools that will allow the reader not only to apply the existing methods but also to develop new ones.

There were several factors that encouraged me to write the book: the advanced time-delay course that I have started to prepare and an invitation from Springer to write a book. Also my brother's experience (Leonid has published a few books) was inspiring.

**Q.** What are some of your interests and activities outside of your professional career?

*Emilia:* For the past 15 years, I have been taking dancing classes. Before dancing, I regularly played piano. Apart from that, I like to read and go to the theater, preferring opera performances in the last few years. Israel is a small country with many talented musicians. We have friends in this community, and we are happy to sometimes organize concerts in our home.

