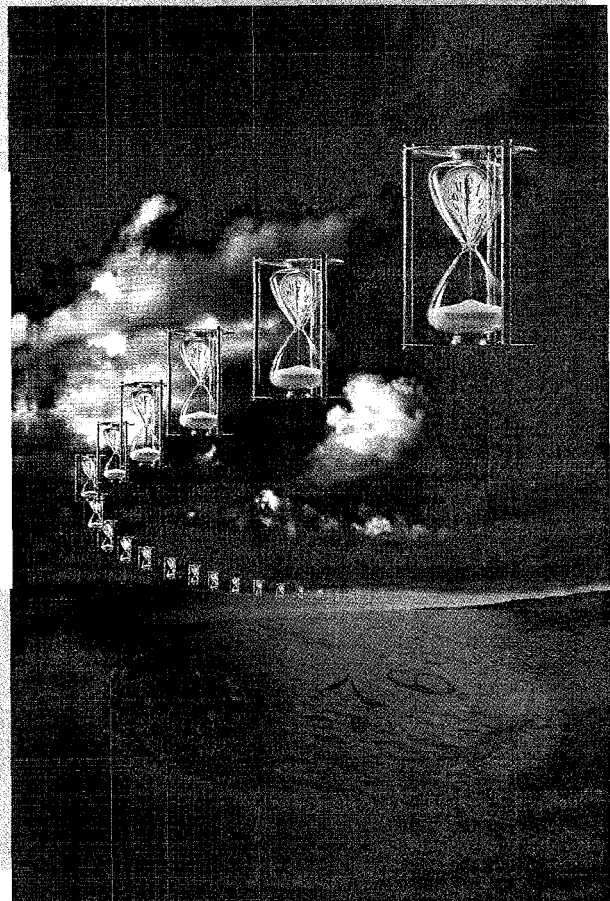# On the History of Control

## A Message from Guest Editor
## Linda G. Bushnell



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The History Committee of the Control Systems Society has certainly been busy this past year. After organizing the first history session at the 33rd CDC in Orlando, Shahram Shahruz and I were drafted into the History Committee by its chair, Mark Nagurka. Shahram and I were already planning a second history session for the 34th CDC in New Orleans, and Mark had a great idea to start interviewing some of the "giants" in the controls field. Moreover, Steve Yurkovich approached me to help as Guest Editor for this special issue of the Magazine to coincide with the IFAC'96.

After the great success of the history session at the 33rd CDC in Orlando, there was sufficient interest to have another such session in New Orleans. We were fortunate to have as speakers Karl J. Åström from the Lund Institute of Technology presenting "Adaptive Control Around 1960" (an expanded version of this paper is included in this special issue of the Magazine), Irwin W. Sandberg from the University of Texas at Austin presenting "Bell Labs in the '60s and Input-Output Stability," Irena Lasiecka from

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the University of Virginia presenting "Control of Systems Governed by Partial Differential Equations: A Historical Perspective," Roger W. Brockett from Harvard University presenting "The Fusion of State-Space and Transform Methods," Arthur J. Krener from the University of California at Davis presenting "The Development of Geometric Theory of Nonlinear Control and Estimation," and Thomas Kailath from Stanford University presenting "Least Squares: Once Again, With Feeling." The session was highlighted in a special evening session and was videotaped for the archives at the IEEE Center for the History of Electrical Engineering at Rutgers University (copies are available upon request). I do not think any of us could have predicted the response to this session. I was told that there were approximately 500 people in the audience.

Katsuhisa Furuta will be carrying on our tradition at the IFAC with a special history session, which will include talks from Katsuhisa Furuta, Tibor Vamos and Jozef Bokor, Stuart Bennett, Chris C. Bissell, Roger W. Brockett, and Lennart Ljung.

In addition, at the 35th CDC in Kobe, Japan, the CSS History Committee will be organizing another special evening session to celebrate the 300th anniversary of Bernoulli's Brachistochrone problem. The talks will cover the calculus of variations, optimal and robust control and will be given by Jan C. Willems, Hector J. Sussmann, John Doyle, and Sergio Bittanti.

## Invited Papers

For this special issue on the history of control. the authors present brief historical accounts focusing on the major and important areas of control. There are seven main articles on the history of automatic control, optimal control, nonlinear control, adaptive control, stability, input-output feedback stability, and filtering and stochastic control.

### Automatic Control

Stuart Bennett's article. "A Brief History of Automatic Control," gives the true flavor of the complete history of automatic control, from the early control up to 1900, through the pre-classical period of 1900-1940 and the classical period of 1935-1960, to the modern control of 1955 and beyond. The early control period included the control of liquid levels, temperatures, pressures, and the speed of rotating machines. The pre-classical period expanded feedback control to voltage, current, frequency regulation, boiler control, electric motor speed control, etc. The classical period began the quest for understanding of control system analysis and design. The modern control period introduced the concept of automatic control.



*From left to right, the participants of the special invited session on History of Control at the 34th CDC: S. Shahruz (session co-organizer), Irena Lasiecka. Karl Åström, Art Krener, Irwin Sandberg, Roger Brockett, Tom Kailath, and Linda Bushnell (session co-organizer).*

### Optimal Control

In Arthur E. Bryson Jr.'s article, "Optimal Control—1950 to 1985," the various areas out of which optimal control grew are discussed. This article is a great source of information for any instructor and student of optimal control. It covers the roots of optimal control in the calculus of variations, classical control, random processes, and nonlinear programming. Other topics discussed include dynamic programming and the maximum principle, calculating nonlinear optimal trajectories, the role of the digital computer in the development of optimal control, singular problems, inverse optimal control methods, and the Riccati equations. The author also includes a discussion of robust optimal control.

### Nonlinear Control

Derek P. Atherton's article, "Early Developments in Nonlinear Control," sets the stage with a discussion on nonlinear control problems prior to 1940 and during WWII, along with the early analytical solution techniques. The article discusses the three main theoretical approaches used for analyzing nonlinear systems during the 1940s to 1960s—the phase plane method, the describing function method, and various methods involving relay systems. At the end of the article there is a section on early simulation and hardware technologies, where we are reminded how much and how fast technology has changed. Also included in this article is a section on early control engineering publications. The article ends with the author's personal account of the topic.

### Adaptive Control

In Karl J. Åström's article, "Adaptive Control Around 1960," you will be caught up in the excitement of the period from the mid-1950s to the mid-1960s. In reading about the important developments, the author brings forth examples from industry and describes the different analytical techniques for adaptive control. The article starts out describing the General Electric and Honeywell adaptive systems for guidance and control, continues with the model reference adaptive control system and self-tuning regulators, and describes the role of optimization in the design of adaptive controllers. The author gives us some of his own personal opinions in the conclusions section, and we are left wanting more.

### Stability

As with any gripping novel, when you start to read Anthony N. Michel's article, "Stability: The Common Thread in the Evolution of Feedback Control," you will not be able to put it down. Major milestones in the development of stability theory in feedback control are described, concentrating on algebraic and geometric stability criteria and frequency domain stability criteria results for linear time-invariant systems, the Lyapunov stability of dynamical nonlinear systems, LaSalle's invariance theorem, and input-output stability. The article covers the period from 1788, with James Watt's invention of the fly-ball governor, to the mid-1970s, with the results of the small gain theorem, the circle criterion, and the passivity theorem.

### Input-Output Feedback Stability

George Zames's article, "Input-Output Feedback Stability and Robustness, 1959-85," gives the reader an inside view on the current problems and various key players of the day. The introduction sets the mood for this adventure, and the story that follows is a fascinating account of the history of input-output feedback nonlinear stability and robustness. The first part of the article deals with input-output stability from 1959 to 1975, starting with the work of Norbert Wiener. The author discusses early research groups, publications, related state-space developments, and more. The second half of the article switches to robustness issues, giving insight into the development of $\mu^Z$ and $\mu^D$ measures, multivariable and multi-block optimization, robust stabilization, and links with system identification.

### Filtering and Stochastic Control

Sanjoy K. Mitter's article, "Filtering and Stochastic Control: A Historical Perspective," presents a technical history of the development of nonlinear filtering and stochastic control. The article covers the development of linear filtering theory from Wiener-Kolmogoroff filtering to Kalman filtering, includes a discussion of the Linear-Quadratic-Gaussian problem of stochastic control, gives a detailed discussion of nonlinear filtering from the innovations point of view, and ends with a discussion of optimal stochastic control—both the fully observable and the partially observable cases. The author complements the article by providing an essential list of references for further information.

### Conclusions

Engineering is for the future, as one of the major contributors to the controls field once told me, but we also can remember, learn from, and be motivated by the past. This special issue of the Magazine gives a brief history of almost all of the important areas of controls. These areas are continuously evolving, being advanced by scientists and practicing engineers today. It is hoped that this genuine and productive interest in history will continue. Furthermore, I hope that all of you have as much fun reading this special issue as we had putting it together.

### Acknowledgments

**Linda G. Bushnell** received the B.S. degree in electrical engineering and computer sciences in 1985 and the M.S. degree in electrical and systems engineering in 1987, both from the University of Connecticut in Storrs. She received the M.A. degree in mathematics in 1989 and the Ph.D. degree in electrical engineering and computer sciences in 1994, both from the University of California at Berkeley. She is the program manager for the Systems & Control Program at the U.S. Army Research Office in Research Triangle Park, NC, and is an adjunct assistant professor in the Electrical and Computer Engineering Department at Duke University. Her personal research interests are in the areas of nonlinear control, with applications to mobile robots and control networks.