Hven and Now

On a Danish island near Copenhagen around 1580, Tycho Brahe (pronounced, roughly, "teeko bra-hee") organized a research center for observing the motion of heavenly bodies and recording data. Around 1627, an assistant to Brahe (now working in Prague) named Johannes Kepler analyzed Brahe's data and, among other things, concluded that the square of the period of each planet is proportional to the cube of the semimajor axis of its elliptical orbit, with the same constant of proportionally for all planets. This claim was based on data; no knowledge of first-principles physics was used. Of what value is such an empirical law?

One use of Kepler's empirical model might be to use a measurement of the period of a newly discovered body to determine its elliptical orbit. But another implication is much more significant. Around 1687 Newton formulated his laws of motion, which allowed him to develop the law of universal gravitation. Kepler's empirical observations provided clues that Newton could use to propose an inverse square law.

Data is the mother of physics. But what is data? Properly interpreted, data is information about the world that we collect and use to understand reality through model building. The science of data-based modeling is called *system identification*.

The special section, Applications of System Identification, of this issue of *IEEE Control Systems Magazine* is a collection of articles with a common theme, namely, that the complexity and uncertainty of many real-world systems can only be overcome by

Contributors

Daniel and Vicky Rivera at the Alhambra in Spain

Jan Swevers with (from left) Bram, Jonas, and Lien. The picture was taken by Jan's wife Annemie
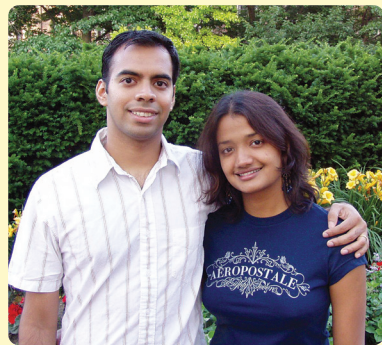

David Bayard with daughters Alexandra and Katie (right) in Yellowstone National Park

Marcelo Espinoza at the 12 Apostles in Australia

Sophia and Spilios Fassois

Harish and Soumya Palanthandalam-Madapusi

collecting data and using it to build empirical models. Rational thought—although essential for interpreting data—cannot alone provide a useful model of the behavior of many systems. For that purpose, data are essential.

To develop and analyze system identification techniques, one can generate fictitious or simulated data ("simdata"). By considering various scenarios involving nonlinearities, noise, and other effects, it is possible—since the "true" system is known—to assess the accuracy of an identification technique. These insights provide a foundation for interpreting the results of system identification performed on real data from a real system whose true characteristics are unknown.

This special section begins with an introductory article by guest editors Spilios Fassois and Daniel Rivera followed by six feature articles. In reading each article, I obtained a fuller appreciation for what it means to do system identification. First, as Spilios and Daniel note in their article, system identification is a discipline that draws on many other disciplines, such as signal processing, statistics, physics, optimization, and systems theory. In addition, the setting and features for system identification problems can be remarkably diverse. Consider, for example, the article by Jan Swevers, Walter Verdonck, and Joris De Schutter, in which their objective is to identify the mass and friction properties of a robot to attain more precise control. Since the robot is under their control, they design and implement experiments to provide information that is useful for model building. Likewise, the article by Daniel Rivera, Hyunjin Lee, Hans Mittelmann, and Martin Braun focuses on the same problem

but within the context of process control. But both applications are challenging since the testing that is used to elicit data from the physical system must be minimally invasive, in short, "friendly."

In another system identification setting, the user has measurements of—but no control over—the inputs to the system and thus is at the mercy of nature in providing useful excitation. This case occurs in the articles by Marcelo Espinoza, Johan Suykens, Ronnie Belmans, and Bart De Moor on forecasting electric power demand, as well as the article by Harish Palanthandalam-Madapusi, Aaron J. Ridley, and myself on forecasting fluctuations of the Earth's magnetic field. In electric power systems, the day of the week and the (terrestrial) weather drive demand, while, in space weather systems, the state of the Sun drives the magnetosphere and ionosphere, and the time of day is relevant. In both cases, inputs are measured (or estimated) but not specified as in the case of identification testing for robot and distillation-column identification.

In yet another setting, the data that drive the system are unknown to the modeler. In particular, in the article by Michele Basseville, Albert Benveniste, Maurice Goursat, and Laurent Mevel, aircraft structural excitation is provided by the turbulence of the surrounding air, and these fluctuations are unknown. Likewise, in the article by David Bayard and Gregory Neat, the drivers that produce sensor noise are unknown. In these applications, the identification is blind, and thus only outputs are available for deducing the behavior of the system.

The diversity of these applications demonstrates that system identification is a rich and challenging field

that provides a direct interface with real systems. Since all data are noisy and all real systems are nonlinear—and no physical system can ever be exactly captured by any mathematical model—it should quickly become clear that much of system identification is as much an art as a science. But, no matter how you look at it, system identification is a branch of systems research whose real-world applicability is never questioned. It is a bridge of iron across the theory-practice chasm.

This issue of *IEEE Control Systems Magazine* includes many other items that we hope you find of interest. In the latest installment of the new department "Ask the Experts," I answer the age-old question "What is hysteresis, anyway?" In "25 Years Ago," Kent Lundberg tells us about the origins of the IEEE Control Systems Society (CSS) logo, which also serves as the story stop at the end of each article in *IEEE Control Systems Magazine*. "People in Control" brings you interviews with Luigi del Re of the Johannes Kepler University of Linz (what a coincidence!) as well as Ian Craig of the University of Pretoria and editor of the IFAC journal *Control Engineering Practice*.

With sadness we publish an obituary of Bill Root, a pioneer in stochastics and a true teacher (one of my own) inside and outside the classroom.

Looking ahead, future issues will continue our series on modeling, while issues on inertial stabilization, friction, and Kalman filtering are under development.

With this October issue, it's time to start making plans for CDC, which this year is in New Orleans. If all 9,000 CSS members attend, it will be the largest CDC ever. In fact, you are welcome to join us, CSS member or not, to help make it a successful and memorable event!

Dennis S. Bernstein