From smart grids to flying robots, engineer finds many applications for theory

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Ricardo Sanfelice Credit: C. Lagattuta

The future of electricity involves a "smart" grid, in which the energy distribution system is fully computerized, with sensors and wireless devices monitoring remote parts of the system and communicating with a central operations center. Automated technology can then adjust and control the components of the grid to improve its efficiency and manage the integration of renewable energy sources.

The intermittency inherent in renewable energy sources such as wind and solar power poses a challenge for electric companies, which must provide a consistent power supply. Smart grid technology could help meet this challenge.

Ricardo Sanfelice, an associate professor of computer engineering at UC Santa Cruz, and his students are developing and testing theories about how to control the flow of electricity through a smart grid. "I have a student writing mathematical equations with one hand and wiring circuits with the other," he said.

To test their theories on a large scale, the researchers will use a smart grid test bed at Sandia National Laboratories in New Mexico. Sanfelice, who recently moved to UC Santa Cruz from the University of Arizona, said he is also interested in collaborating with local utility companies and other companies working toward the future smart grid.

Hybrid systems

The complex dynamical behavior of smart grid systems is partly due to the combination of two kinds of behavior: continuous changes and abrupt jumps in currents and voltages. Sanfelice specializes in understanding and controlling such "hybrid systems" in which continuous and discrete behavior is intertwined. Hybrid systems often involve both analog and digital components or so-called "cyber-physical systems," in which embedded computers and networks monitor and control physical elements or processes.

A simple example of a hybrid system is a thermostat programmed to keep the temperature in a room constant. Changes in temperature occur in a continuous manner, steadily dropping in cold weather, for example, until the temperature drops below the set point. Then a heater kicks on to warm the room, providing an abrupt or discrete change in the system that occurs at irregular intervals as the thermostat switches the heater on and off.

Scientists previously modeled such hybrid systems by treating them mathematically as either continuous or discontinuous systems. But Sanfelice says many problems can only be understood by considering both aspects of a hybrid system.

Aerial robots

The control of flying robots or drones is another area in which Sanfelice applies hybrid systems analysis. When an aerial robot flies inside a building from an outdoor area, it has to make several sudden adjustments. The navigation system, for example, might switch from using GPS outdoors to onboard cameras indoors. The flight system also has to accommodate changes in airflow and pressure as the device moves through a doorway or window into a building.

Sanfelice hopes to expand the robotics applications of his research at UCSC by partnering with robotics companies in the area. His lab will have space to test their computational theories using ground-based and aerial robots in a controlled setting. One of his main interests is in networks of robotic or autonomous systems in which computer algorithms have to make decisions in response to changes in the network.

Sanfelice also sees examples of hybrid systems in nature in areas such as neuroscience, and he's hoping to tackle the theory behind these problems as well. Spikes of activity caused by neurons firing together may contribute to the symptoms of Parkinson's disease, for example. Using theory to understand that synchronicity could suggest ways to desynchronize the firing, Sanfelice said.

Synchronized fireflies

Another example of a hybrid system found in nature is the synchronized flashing of fireflies. If each firefly has an internal timer that resets each time it flashes and also resets in response to flashes from other fireflies, the light show can begin with flashes from just one or a few fireflies. As others in the group see the light and reset their internal timers, their timers will eventually synchronize, so that all the fireflies flash together.

Sanfelice has worked out mathematical equations to determine when synchronization will happen, how fast it happens, and what happens when new fireflies join the group. Students in his cyber-physical systems class are using those equations to create a "virtual firefly" app for mobile phones. Phones with the app installed would communicate with each other so that, once activated, the screens on a few phones randomly light up and, over time, all of the phones flash together.

"This effort is relevant to event-based synchronization in network systems, such as the need to synchronize the time of multiple computers over large data networks," Sanfelice said.

Though he enjoys figuring out the mathematics to describe hybrid systems, Sanfelice also feels it's important to use those equations for practical applications. "I get excited when there's a system I can understand and contribute to a problem that is relevant," he said.

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