The Many Faces of Control

As I reviewed the list of past presidents of the IEEE Control Systems Society (CSS), I was struck by the wide array of backgrounds that they represented, including both academic and industrial careers. However, it would appear that I am the first chemical engineer who has been picked to serve as the president of the IEEE CSS. Although I am a chemical engineer by training and degree, my professional appointments have included electrical engineering and bioengineering departments in universities, as well as a research and development group in industry (at DuPont). I do not think that my situation is unusual; quite the contrary, the current cohort of undergraduate and graduate students in universities around the world are immersed in richly interdisciplinary curricula that transcend traditional boundaries. Many of our colleagues in universities migrate readily across engineering and applied sciences with both their appointments and their collaborations.

On reflection, it is hardly surprising that a chemical engineer would lead the IEEE CSS, given the many faces of control, which has been called the "invisible technology." Control applications are manifest in such diverse fields as aerospace engineering, manufacturing, biomedical devices, process systems, transportation systems, and nano/microscale devices. Every modern appliance or piece of technology, from our smart watches, to our dishwashers, to our automobiles is enabled by (often layers of) control-systems technology. The engineers

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and scientists that design and analyze such systems are trained in an equally wide range of academic disciplines, including mathematics, electrical engineering, operations research, civil engineering, computer science, industrial engineering, mechanical engineering, applied mathematics, bioengineering, and, of course, chemical engineering. Our colleagues in Europe and Asia widen that list even further to include more specialized departments and degrees in cybernetics, automation, and control engineering. It is curious that few programs in the United States have focused on the control or systems field for naming a department, with notable exceptions at Boston University (Systems Engineering) and Washington University (Systems Science and Engineering). However, a far wider list of schools offer degrees in systems engineering [1]. According to the 2015 directory of academic programs published by the International Council on Systems Engineering (INCOSE) [2], there are over 140 academic programs in North America, over 40 in Asia, and over 30 in Europe [2].

The individual departments in this diverse spectrum of academic disciplines are certainly differentiated by their specific applications, which tie more closely to the discipline (for example, pulp and paper plants in chemical engineering and automobiles in mechanical engineering). Time scales are another differentiating factor that ties closely to traditional disciplines and their corresponding applications, from nanosecond requirements in computer control, to milliseconds in traction control, to minutes in refinery operations, to weeks in industrial production scheduling and planning [3]. However, the power of this community lies in the overlapping combination of a core set of fundamental skills that distinguish a control scientist or control engineer, independent of his specialized field. Those core principles include feedback mechanisms, system dynamics, modeling and simulation, estimation, and optimization. These undergirding elements provide a firm foundation and also point to the broad applicability of these skills. I am hard pressed to think of another subtopic (such as thermodynamics or fluid mechanics) that cuts across such a wide array of applied science and engineering disciplines.

Indeed, many of the grand societal challenges of our time lend themselves

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The "many faces of control" are well prepared to serve on multidisciplinary teams to develop a better understanding of these issues.

CONCLUSION

I hope this column has convinced readers of three things: that IoT is more than a buzzword, that control expertise will be required to realize the visions of IoT that the promoters of the field are promising, and that IoT brings new and exciting opportunities for research and development in control science and engineering. To illustrate the last assertion, here are some prospects that can motivate our research [5]:

- Systems that are not physically connected or collocated could be coordinated in real time.
- Optimized performance (such as energy efficiency) could be achieved for small-scale systems that cannot afford dedicated control systems.
- High-fidelity models could be widely applied for real-time control via cloud-based implementations.
- Global networks of sensors and actuators could be implemented and coupled with sophisticated control and optimization algorithms.
- Greater redundancy and fault tolerance could be achieved across critical infrastructures.

IEEE has launched an IoT initiative (http://iot.ieee.org), supported by several IEEE Societies including the IEEE Control Systems Society (CSS). All IEEE Members can join the IEEE IoT Technical Community and subscribe to the free IoT newsletter published by IEEE IoT. The CSS engagement is through the Technical Committee (TC) on Networks and Communications (http://networks-and-communications.ieeecss.org/). The TC chair, Daniel Quevedo, is a member of the IEEE IoT Steering Committee (as am I). Readers interested in being involved in control systems and the IoT are encouraged to participate in the TC.

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naturally to control and systems approaches, including the production of sustainable energy, the implementation of affordable and effective health care, automated manufacturing, and the societal implications of the growing databases that live in the cloud. Some of the themes that link these seemingly disparate challenges are the reliance on "big data," the need for more effective sensors, requiring novel materials for hardware, and the characterization and management of uncertainty.

The "many faces of control" are well prepared to serve on multidisciplinary teams to develop a better understanding of these issues and, furthermore, to formulate and develop solutions for these challenging opportunities. I will return to this theme over the course of the year in this column, and I welcome comments from this community on novel classes of problem that are yielding to systems and control solutions.

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