

In this issue of *IEEE Control Systems Magazine*, we speak with six IEEE Fellows in the control systems field.

Ratnesh Kumar is a professor in the Department of Electrical and Computer Engineering at Iowa State University. Previously he was on the faculty at the University of Kentucky and has held visiting positions at the University of Maryland, the Applied Research Laboratory at Pennsylvania State University, NASA Ames Research Laboratory, Idaho National Laboratory, and United Technologies Research Center. He received a B.Tech. in electrical engineering from India Institute of Technology Kanpur in 1987 and an M.S. and Ph.D. in electrical and computer engineering from the University of Texas, Austin, in 1989 and 1991, respectively. He serves or has served as an editor of *SIAM Journal on Control and Optimization*, *IEEE Transactions on Robotics*

and *Automation, Journal of Discrete Event Dynamical Systems, International Journal on Discrete Event Control Systems*, and *IEEE Transactions on Automation Science and Engineering*, and on the program committees of numerous conferences.

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Ratnesh Kumar in front of the sculpture outside the ECpE building at Iowa State University.

RATNESH KUMAR

Q. How did your education and career in the control field develop?

Ratnesh: My interest in controls was sparked by being in the Department of Electrical and Computer Engineering at the University of Texas, Austin (UT-Austin) as a Ph.D. student and by being inspired by the great controls researchers there, Steve Marcus (who eventually mentored me, along with Vijay K. Garg), Aristotle Arapostathis, Irwin Sandberg, and Yu-Chi Ho (who at the time was visiting UT-Austin

from Harvard). I started out by taking courses in controls, information theory, image processing, neural networks, theory of computer programming, network protocols, and distributed computing and eventually settled into the interface of controls and computer science (so-called *cyberphysical systems*). This research was stimulated in part by an exposure to the then-emerging field of discrete-event systems (DESs) at the 27th IEEE Conference on Decision and Control in Austin, during my third semester at UT-Austin. I went over the DES-related papers in the proceedings and could see opportunities for immediate contributions. It happened that

Steve Marcus had already supervised a Ph.D. student on the topic, and I was fortunate to have an advisor conversant in the field. The very first journal paper I wrote was coauthored by W.M. Wonham, whose pioneering paper had started the field. My interests in controls continued with the establishment of new collaborations such as with Mark Shayman at University of Maryland (thanks to Steve Marcus for establishing the opportunity, who had been appointed as the director of a National Science Foundation Engineering Research Center there), and Michael Heymann at NASA Ames Research Center (visiting from the Technion,

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Israel). My work until this point has remained grounded in theory.

The exposure to practical problems started through collaborations with James Stover and Sekhar Tangirala at the Applied Research Laboratory (ARL) at Pennsylvania State University (thanks to Asok Ray of Penn State for fostering the opportunity) on the problems of mission-level intelligent control of autonomous underwater vehicles. My DES background was valuable in the modeling and verification of mission-control systems, and this work further provided entry into the field of formal verification of logical (e.g., software) as well as stochastic systems (e.g., physical systems). The work on safety problems for stochastic systems at the ARL led to collaboration with Aristotle Arapostathis of UT-Austin. By this time, my first Ph.D. student, Shengbing Jiang, who had graduated and was at General Motors Research and Development (GM R&D), provided industrially motivated problems for collaboration on software fault tolerance and issues of computation/communication delays/jitters on program semantics. Since then, several other Ph.D. students and postdocs have found placement in industry:

- » Changyan Zhou worked on topics of bisimulation control, and model-based test generation for Simulink/Stateflow (Magnatech).
- » Wenbin Qiu worked on decentralized diagnosis and estimation of DESs (Corning).

- » Songyan Xu worked on the effect of finite-precision clocks on real-time control/diagnosis.
- » Siddhartha Bhattacharyya worked on formal modeling and verification of mission-control of underwater vehicles (Rockwell).
- » Zhongdong Huang worked on the symbolic approach to fault detection of DESs (LHP Software).
- » Jing Huang proposed the notion of *directed control* of DESs (Freescale).
- » Qin Wen worked on fault-tolerant control of DESs (Controls & Statistics).
- » Saayan Mitra worked on choreography for Web services (Adobe).
- » Herman Sahota worked on sensor networks for precision agriculture (IBM).
- » Licheng Jin worked on model predictive control of power systems (California ISO).
- » Lucien Ouedraogo worked on response time computation in embedded networks such as FlexRay (MathWorks).

Other Ph.D. students—Vigyan Chandra, who worked on the symbolic approach to modeling DESs, and Jeff Ashley, who worked on diagnosis of concurrent DESs—joined academia (Eastern Kentucky University and the University of Kentucky, respectively).

I started my academic career at the University of Kentucky in 1991, and in 2002 I joined Iowa State University. This transition was inspired by the opportunity to diversify, and indeed the move led to new collaborations in areas such as power systems (James McCalley), networks (Ahmed Kamal), sensor electronics (Robert Weber), and software engineering (Samik Basu). I have already mentioned fruitful visits and collaborations at the University of Maryland (summers of 1992 and 1994), NASA Ames Research Center (summer of 1996), and ARL at Penn State (1997–1998). During my year at ARL, Pravin Varaiya visited as a distinguished lecturer. Later, at his invi-

tation, I spent few weeks at the University of California, Berkeley, looking at model-based code generation and verification tools that his group had developed (this was the period of his directorship of the PATH project) and applying these tools to the context of mission control of underwater vehicles at ARL.

My next extended visit was in summer of 2001, when I was at the Idaho National Laboratory and collaborated with Humberto Garcia on problems of routing errors in materials-handling systems (of importance to the nuclear industry). In the summer of 2008, I visited Chalmers University in Sweden where I, along with Knut Akesson and Robi Malik (visiting from the University of Waikato), developed a symbolic control method for DESs. Later in 2008–2009, I visited United Technologies Research Center (thanks to the efforts of Guido Poncia) and worked with their embedded systems group on the problems of correct-by-construction wireless network synthesis, along with Alessandro Pinto.

In 2009–2010, I collaborated with a number of researchers from Carnegie Mellon University, Massachusetts Institute of Technology, and the big three automakers to develop a USCAR report for software fault tolerance. In 2011–2012, I joined hands with colleagues from AFRL, University of Pennsylvania, Vanderbilt University, and Galois to put forward an Air Force Research Laboratory report on runtime verification. My other longstanding collaborators include Shigemasa Takai of the University of Osaka, Martin Fabian of Chalmers University, and S. Ramesh of GM R&D.

Q. What are some of your research interests?

Ratnesh: My current research interests are formal approaches for event-driven, real-time, and hybrid systems and their applications to cyberphysical systems, embedded systems and software, Web services, security, and power systems. For example, currently we are developing

methods and tools for model-based automated test generation for Simulink/Stateflow software (with Meng Li), an approach for software and cyberphysical system fault detection (with Jun Chen), an efficient technique for verifying linear hybrid systems (with Hao Ren), and approaches for information flow security (with Mariam Ibrahim). In our group, we are also looking at the design of in-situ soil sensors (with Gunjan Pandey) for sustainable agriculture and underground energy harvesting (with Kanishka Singh). A further direction involves Bigdata research, with application to video prediction/recommendation (with Gang Wu), in collaboration with Adobe.

Q. What courses do you teach relating to control? How would you describe your teaching style?

Ratnesh: I have introduced and taught courses on DESs and formal verification of software. I do teach the standard courses on linear/nonlinear/optimal/digital control, signals and systems, circuits, and discrete mathematics. When I was exposed to control research/teaching during my graduate studies, it was grounded in theory, which was fun, but felt that the connection to the real world was missing. I like to expose the students to a balanced approach involving theory and also algorithms for real-world applications. Through exposure to projects, industry internships, and hands-on tools (as Simulink/Stateflow and NuSMV), enhanced learning and understanding of the hidden engineering issues has become practical reality.

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

Ratnesh: The notions of inputs, outputs, states are all pervasive, and the control is continuing to evolve in all kinds of domains and disciplines, which is fascinating. Understanding

Profile of Ratnesh Kumar

- *Current position:* professor, Department of Electrical and Computer Engineering and Department of Computer Science, Iowa State University.
- *Visiting and research positions:* University of Maryland at College Park, NASA Ames Research Center, Applied Research Laboratory at Pennsylvania State University, Idaho National Laboratory, United Technologies Research Center.
- *Contact information:* Electrical and Computer Engineering, Iowa State University, 2215 Coover Hall, Ames, Iowa 50011-3060, +1 515 294 8523, fax: +1 515 294 8432, rkuma@iastate.edu; <http://home.eng.iastate.edu/~rkumar>.
- *IEEE experience highlights:* editorial board, *IEEE Transactions on Robotics and Automation* (2000–2002); program committees (multiple years) of IEEE Conference on Decision and Control, IEEE International Conference on Automation Science and Engineering, IEEE International Conference on Emerging Technologies and Factory Automation, and IEEE International Symposium on Intelligent Control.

ways of controlling complex distributed systems of components within computation and communication limitations, while operating in uncertain environments, continues to be a challenge that must rely on sound theoretical and scalable algorithmic approaches. Controls does not exist in isolation, and so being able to inculcate a systems view is important for controls researchers to contribute to interdisciplinary topics, such as the National Academy of Engineering challenge topics. Developing enabling mechanisms for handling such systems is important and would involve community-wide effort.

Q. You are the author of one book in the control field. What topics does this book cover?

Ratnesh: I entered the field of DESs during its infancy. While it had many opportunities to grow, initially the number of researchers was limited, and so in the beginning it was challenging to find an academic position and research funding. To promote the awareness of the field, within four years of my Ph.D., I, along with my comentor, Vijay Garg, wrote the textbook *Modeling and Control of Logical Discrete Event Systems*, which was published by Kluwer Academic Pub-

lishers (now part of Springer). [Kluwer had already invested in the field, by launching a new journal dedicated to the topic, under the leadership of Y.-C. Ho.] The book introduces formal languages and automata, lattices and fixed point computations, and controllability and observability for DESs and their modular/decentralized/infinitary versions.

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

Ratnesh: Life has many facets, and family and career have been at the top. Besides the activities with our two boys, music and poetry, sports (soccer), hiking and biking in nature, and watching what Bollywood (and Hollywood) has to offer are some fun ways of rejuvenating the mind, body, and soul, in an aspiration to lead a life (hopefully) at the cutting edge of fulfillment.

Q. Thank you for your comments.

Ratnesh: Thanks to you as well. I really appreciate the opportunity to share my journey in control, and acknowledge key collaborators, by whose side and shoulders, I could attain a more panoramic vista, along the continuing journey.