This issue of *IEEE Control Systems Magazine* (*CSM*) speaks with the following IEEE Control Systems Society (CSS) members: Bijnan Bandyopadhyay, who was elevated to the rank of IEEE Fellow in 2018; Jeff Peters, the IEEE CSS liaison to the global IEEE Young Professionals organization; Santosh Devasia, who recently was chosen as the general chair of the 2020 American Control Conference (ACC); and Michael G. Ruppert and S.O. Reza Moheimani, who coauthored the paper that received the IEEE Transactions on Control Systems Technology Outstanding Paper Award in 2018.

Bijnan Bandyopadhyay is an Institute Chair Professor and head of the Systems and Control Group, Indian Institute of Technology (IIT) Bombay, India. He received the B.E. degree from the Indian Institute of Engineering Science and Technology, Shibpur, India (formerly Bengal Engineering College, Calcutta University), in 1978 and the Ph.D. degree from IIT, Delhi, in 1986. He was with the Lehrstuhl fur Elecktrische Steuerung und Regelung, Bochum, Germany, as an Alexander von Humboldt fellow and was awarded distinguished visiting fellow by the Royal Academy of Engineering, London, in 2009 and 2012. He has authored over 400 publications, including monographs, book chapters, journal articles, and conference papers. He has guided 36 Ph.D. theses at IIT Bombay. His research interests include multirate output feedback-based, discrete-time sliding mode control (SMC); event-triggered SMC; and nuclear reactor control. He was cochair of the International Organization Committee and chair of the Local Arrangements Committee for the 2000 IEEE International Conference on Industrial Technology (ICIT), one of the general chairs of the 2006 IEEE ICIT, and general chair for the 2012 IEEE International Workshop on Variable Structure Systems and Sliding Mode Control. He is currently a technical editor of *IEEE/ASME Transactions on Mechatronics* and associate editor of *IEEE Transactions on Industrial Electronics* and *IET Control Theory and Application*. He is a Fellow of the IEEE and the Indian National Academy of Engineering.

Jeff Peters is a senior research engineer in the Autonomous and Intelligent Systems Department, United Technologies Research Center, East Hartford, Connecticut. Since 2017, he has also served as the CSS liaison to the global IEEE Young Professionals organization. He received the B.S. degree in mechanical engineering from the University of Illinois, Urbana-Champaign, in 2011 and the M.S. degree in mechanical engineering, the M.A. degree in applied mathematics, and the Ph.D. degree in mechanical engineering from the University of California, Santa Barbara (UCSB), in 2013, 2015, and 2017, respectively. He is the author of numerous journal and conference proceedings articles, and his work has appeared in IEEE publications such as *IEEE Transactions on Control Systems Technology* and *IEEE Control Systems Magazine*. His research interests are in the development, analysis, and implementation of algorithms for both the synthesis and coordination of effective multiagent systems. He also has broad interests in optimization, machine learning, and applied data science.

Santosh Devasia is a professor of mechanical engineering at the University of Washington (UW), Seattle. He received the B.Tech. degree (Hons) from IIT, Kharagpur, in 1988 and the M.S. and Ph.D. degrees from UCSB in 1990 and 1993, respectively. He was associate dean of Research and Faculty Affairs, College of Engineering, UW, from 2014 to 2017. Currently, he is the director of the Boeing Advanced Research Center at UW, which focuses on the manufacturing and assembly of aircraft and spacecraft structures. He was an associate editor for the American Society of Mechanical Engineers (ASME) *Journal of Dynamic Systems Measurement and Control* and *IEEE Transactions on Control Systems Technology*. He has been on several major conference-organizing committees and is the general chair for the 2020 ACC and the 2023 International Conference on Advanced Intelligent Mechatronics. He has published over 80 papers in archival journals and 95 papers in refereed conference proceedings. He is a Fellow of the IEEE and ASME. His current research interests include the theory of iterative control and distributed systems and applications in human–machine interaction, mechatronics, manufacturing, and robotics.

Michael G. Ruppert is a postdoctoral research fellow at the University of Newcastle, Australia. He received the Dipl.-Ing. degree in automation technology in production, with a specialization in systems theory and automatic control, from the University of Stuttgart, Germany, in 2013. In 2017, he received the Ph.D. with Excellence Award in electrical engineering from the University

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of Newcastle. He was a visiting researcher in the Mechanical Engineering Department, University of Texas (UT) at Dallas. He is an associate editor for the CSS Conference Editorial Board. His research has been recognized with best conference paper finalist awards at the 2018 International Conference on Manipulation, Automation, and Robotics at Small Scales and the 2013 IEEE/ASME International Conference on Advanced Intelligent Mechatronics. In 2018, he received the 2018 IEEE Transactions on Control Systems Technology Outstanding Paper Award. His research topics are in the area of microprecision mechatronics and, as such, bridge the gap between classical electrical/control engineering and emerging applications in the field of microelectromechanical systems, high-performance microscopy, and nanotechnology. His recent work has focused on the development of estimation, control, and self-sensing approaches for piezoelectric microcantilevers and nanopositioning systems for multifrequency and single-chip atomic force microscopy.

S.O. Reza Moheimani is the James Von Ehr Distinguished Chair in Science and Technology and professor at UT Dallas. He received the B.Sc. degree from Shiraz University in 1990 and the M.Eng.Sc. and Ph.D. degrees from the University of New South Wales in 1993 and 1996, respectively. Prior to joining UT Dallas in 2015, he was a professor and Australian Research Council Future Fellow in the School of Electrical Engineering and Computer Science at the University of Newcastle, Australia. During his 18 years with the University of Newcastle, he established a research program in the area of high-precision mechatronic systems with significant national and international collaborations and served as an associate director of the Center for Complex Dynamic Systems and Control, an Australian Research Council Center of Excellence. His honors include the IEEE Transactions on Control Systems Technology Outstanding Paper Award (twice), the IFAC Nathaniel B. Nichols Medal, the IFAC Mechatronic Systems Award, the IEEE CSS Control Systems Technology Award, and Fellow of IEEE and the IFAC. His current research interests are in the control of high-precision mechatronic systems, high-speed scanning probe microscopy, and atomically precise manufacturing.

Jonathan P. How

BIJNAN BANDYOPADHYAY

Q. How did your education and early career lead to your initial and continuing interest in the control field?

Bijnan: I did my schooling at Birbhum village in West Bengal, India. I had a strong interest in mathematics, and that was further nurtured by my mathematics teacher, Prafulla K. Roy Chaudhuri and headmaster Paritosh Khan. Both teachers motivated me to learn more mathematics by teaching advanced topics and introducing me to several good books on algebra and geometry. After my schooling, I attended Bengal Engineering (B.E.) College, Calcutta, India, the oldest degree engineering college in India (established in 1856). I studied electronics and telecommunication engineering, a popular discipline for students in those days. However, I completed a large number of courses in mathematics at B.E. College. In my final year of study, a basic course on control systems was taught by Dr. Amitava Mustafi, which generated a huge interest in the subject. His command of the

Bijnan Bandyopadhyay (back row, sixth from right) is shown with his former and current Ph.D. students at IEEE Variable Structure Systems 2012, held at Indian Institute of Technology Bombay.

English language and his knowledge of the subject inspired me to learn a lot more about it.

Fortunately, I was selected to pursue my Ph.D. degree in control systems at the Indian Institute of Technology (IIT) Delhi directly after completing my undergraduate program. I was again fortunate to get an opportunity to work under Prof. S.S. Lamba, a well-known professor in control systems in India. His keen interest in model order reduction motivated me to research this topic. Throughout the Ph.D. program, he was very systematic and methodical in his approach. He initially advised me to complete a number of courses on control systems, such as state-space analysis, control system design, optimal control, stochastic control, system identification, and linear algebra. These classes helped me a great deal to build a sound foundation in control systems. His guidance included an enormous amount of time every week discussing the research problem, its progress, and future directions. From him, I learned the skill of good technical writing, with an emphasis on writing in a brief and concise manner. In particular, this has helped me a great deal to write research papers.

I also met a few well-known professors (A.K. Mahalanabis, S.C. Dutta Roy, S.I. Ahson, and M. Gopal), whose advice helped to shape my research career immensely. After a stint at the Delhi Institute of Technology, I joined the systems and control group at IIT Bombay, where I met Prof. M.C. Srisailam, a promising professor of nonlinear and adaptive control. Even though I was a faculty member, I used to sit through some of his lectures, which proved to be highly beneficial. He was an extremely gentle and knowledgeable person. While there, I had an opportunity to advise Ph.D. students. I was involved in the work of simultaneous stabilization of more than two plants with my first Ph.D. student, S. Jayakumar. I observed that Ph.D. advising is also a process of learning, by which I tried to learn what simultaneous stabilization was.

Bijnan Bandyopadhyay (center) with his family in the majestic valleys of Kashmir, India.

At the same time, I began advising two more students, A.K. Paul and A.P. Tiwari, both of whom were scientists from the Bhabha Atomic Research Center, Mumbai, India. In doing so, I was fortunate again to work on practical control systems. In a few years, I also successfully advised the M.Tech project of A.K. Paul on sliding mode control (SMC) for a printed circuit dc motor and helped to move the Ph.D. thesis work of A.P. Tiwari on the modeling and control of large-size nuclear reactors to an advanced stage.

SMC has fascinated me due to its simple structure and robustness. I thought I must pursue research in this area. In the meantime, I was offered the Alexander von Humboldt Fellowship from Germany and was fortunate to work with Prof. Heinz Unbehauen of Ruhr University of Bochum. By that time, we had modeled the large-size nuclear reactor by a 70th-order state-space model, which was the first of its kind. This reactor has only 14 outputs available for measurement. My student, A.P. Tiwari, and I investigated how to stabilize the reactor using only output information. It was a coincidence that I met Dr. Herbert Werner in Unbehauen's lab, with whom I was discussing the problem of stabilization of our reactor using only output feedback. Dr. Werner had just completed his Ph.D. with Prof. K. Furuta of Tokyo University and joined the Control Institute of Ruhr University. He gave me his thesis to read and told me that I would get the answer to how the static kind of output feedback can stabilize this 70th-order nuclear reactor. I returned from Germany after 1.5 years and shared the idea with my student A.P. Tiwari.

Since then, I have investigated how this output sampling technique could be useful for discrete-time SMC. I assigned this problem to two students, M.C. Saaj and S. Janardhanan, and we successfully addressed the bottleneck of SMC using output feedback. Discrete-time SMC was a favorite research area of my group for several years. By this time, research on higher-order SMC gained more importance due to its superior properties over traditional SMC. At this time, I met Prof. Leonid Fridman and Prof. Jaime Moreno. Through an Indo-Mexican research project (which included stimulating discussions, lectures, and short schools between my group and the Mexican group), my own knowledge of higher-order SMC and that of my students (Prasiddh Trivedi, Shyam Kamal, Asif Chalanga, and M.D. Patil) were enriched. From 2009 to 2012, I also had very fruitful collaborative work with Prof. Sarah Spurgeon of the University College London, through my visit as a distinguished visiting fellow of the Royal Academy of Engineering, London.

Visit to Shalimar and Nishat Bagh in Srinagar at Kashmir.

Prof. Fridman (right) wishing Bijnan Bandyopadhyay (left) well on his 60th birthday at the IEEE Fall School on Modern Systems, Man, and Cybernetics, held at the Indian Institute of Technology Bombay in 2016.

Recently, I thought about how the sliding mode idea can be viewed from an event-triggered control perspective, and a very significant result has been obtained with my Ph.D. student, Abhisek K. Behera. This resulted in a new definition of "practical sliding mode," which can result when SMC is applied in an event-triggered manner. I also collaborated with Prof. Xing Yu of RMIT, Australia, for discrete implementation of event-triggered sling mode control.

Since then I am sliding on a sliding manifold, so to speak!

Q. What are some of your research interests?

Bijnan: I was initially interested in the area of model order reduction and controller design using a reduced order model. Later, my interests shifted to the development of a new theory and algorithm on discrete-time SMC using a multirate output sampling technique. I was also interested in the development of a mathematical model for large-size nuclear reactors, such as pressurized heavy water reactors and advanced heavy water reactors, and the application of a multirate technique based on SMC to these reactors. My current research interest is on event-triggered SMC and how this idea is useful for a networked control system, given the delay and failure in the network.

Q. What courses do you teach relating to control? Do you have a favorite course? How would you describe your teaching style?

Bijnan: At our institute, we have two semesters in a year, autumn and spring. At present, I teach control-related courses in both the semesters. In the autumn semester, I teach a fundamental course, such as the modeling of dynamical systems and system identification. In the first part of the course, I teach the basic tools for modeling. In the second part, I discuss modeling of various physical systems drawn from real-world problems across disciplines. One important feature of this course is that it is taken by students from various backgrounds, including electrical engineering, mechanical engineering, aerospace engineering, and chemical engineering.

In the spring semester, I teach a basic course on signal and feedback systems for the students of the minor program in systems and control and an advanced course on variable structure systems and SMC. I introduced this course at IIT Bombay. I begin from the basics of variable structure systems and move to the advances and recent results on SMC.

As the course includes recent results on SMC, students must refer to many research papers. Thus, they find the course somewhat difficult. However, they get thorough, detailed information on this topic in one place, and it becomes very beneficial for those who aspire to pursue a Ph.D. degree in this area. I try to put these advanced topics in a simple manner, which is highly appreciated by the students and is further evident in high course evaluations.

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

Bijnan: I see that control theory has enormous scope for application to practical fields. As important as the development of control theory is, equally important is the fact that control theory connects society more to solve real-world problems. I see there are ample avenues for the application of control to real-world problems, such as smart grids, network control systems, and space applications.

Q. You are the author of eight books in the control field. What topics do these books cover?

Bijnan: My first monograph, *Discrete-Time SMC: A Multirate Output Feedback Approach* (Springer-Verlag, 2006), deals with the theory of multirate output feedback-based SMC, discretization of SMC, and the application of the technique to practical systems.

The second monograph, *Modeling and Control of Smart Structure* (Springer-Verlag, 2007), thoroughly discusses the modeling of a smart beam with a piezoelectric sensor and actuator using the finite element technique. It examines the optimal location of a sensor/actuator on a smart beam. It also discusses the vibration control of a smart beam using output feedback.

The third monograph, *SMC Using Novel Sliding Surfaces* (Springer-Verlag, 2009), deals with the proposal of nonlinear sliding surfaces. When the system is in sliding mode, damping of the system changes continuously by including a negative function in the sliding surface. This ensures that, in the initial part, there will be less damping so that the response speeds up. In the final part, the system becomes heavily damped, which minimizes the overshoot. The monograph also discusses SMC with actuator saturation.

The fourth monograph, *Modeling and Control of Advanced Heavy Water Reactor* (Springer-Verlag, 2013), contains the results of modeling and control of advanced heavy water reactors. A 90th-order model was developed. In addition, the state and output feedback controllers were designed by decomposing this model into slow, fast, and faster models using three timescale theories.

The fifth monograph, *Advances in SMC* (Springer-Verlag, 2013), is an edited collection of plenary and invited talks delivered at the 12th IEEE International Workshop on Variable Structure Systems (VSS) and SMC, held at IIT Bombay in January 2012. The workshop organizers, together with the IEEE Control Systems Society Technical Committee on Variable Structure and SMC, invited leading international researchers to present plenary and invited talks to articulate the current state of the art, both in terms of theory and practice in the discipline. After the workshop, researchers were invited to develop book chapters for this edited collection.

Profile of Bijnan Bandyopadhyay

- *Current position:* Institute Chair Professor and convener, systems and control, Indian Institute of Technology, Bombay.
- *Visited universities:* invited faculty at the Center for System Engineering and Applied Mechanics, University of Louvain, Belgium. Visited Ruhr University of Bochum; Technical University of Ilmenau, Germany, as an Alexander von Humboldt fellow; Korea Advanced Institute of Science and Technology as a visiting professor; and University of Canterbury, U.K., as a distinguished visiting fellow of the Royal Academy of Engineering, London.
- *Contact information:* Indian Institute of Technology Bombay, Room 208, Interdisciplinary Program in Systems and Control Engineering, bijnan@sc.iitb.ac.in; http://www.sc.iitb.ac.in/~bijnan/.
- *IEEE Control Systems Society experience highlights:* member, Technical Committee on Variable Structure System and Sliding Mode Control (2010–present); general chair, IEEE International Workshop on Variable Structure System and Sliding Mode Control (2012), IEEE Fall School on Modern Sliding Mode Control (2016).
- *Notable awards:* Alexander von Humboldt Fellowship (1995); Distinguished Visiting Fellowship, Royal Academy of Engineering London (2009 and 2012); U.K.–India Education and Research Initiative Major Award (2007); Fellow, IEEE (2018), Indian National Academy of Engineering (2007).

The sixth monograph, *Frequency Shaped and Observer-Based Discrete-Time SMC* (Springer, 2015), proposes a method for multirate frequency-shaped SMC design based-on a switching and nonswitching type reaching law. The frequency-dependent compensator dynamics were introduced through a frequency-shaped sliding surface, by assigning frequency-dependent weighing matrices in a linear quadratic regulator design procedure. The monograph also presents the design of discrete-time reduced-order observers using the duality to discrete-time sliding surface design.

The seventh monograph, *Stabilization and Control of Fractional Order System: A Sliding Mode Approach* (Springer-Verlag, 2015), deals with the stabilization and control of continuous and discrete fractional-order systems. The monograph stresses the need for SMC for fractional-order systems. It addresses the question of how to define the solution of a fractional-order differential equation with a discontinuous right-hand side. The latter part of the book deals with the finite time stabilization of a chain of uncertain fractional-order integrators. The text also deals with the higher-order and discrete SMC for a fractional-order system.

The eighth monograph, *Event-Triggered Systems, Men, and Cybernetics* (Springer-Verlag, 2018), deals with a new approach for SMC design using a novel implementation strategy, namely event triggering. In this strategy, the control is updated whenever a certain stabilizing condition is violated, and hence the system stability is always maintained. The design of event-triggered SMC for both linear and nonlinear systems is presented. The monograph also presents the results on SMC design using a self-triggering strategy. Finally, the design of event-triggered SMC with quantized state measurements is presented.

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

Bijnan: I have a small family. My wife has a doctorate in Sanskrit (Rg. Veda), and she teaches in a higher secondary school near IIT Bombay.

My daughter is completing her M.S. degree in electrical system engineering at the University of Paderborn, Germany. We go out to hill stations and sea shores for a change, whenever we get time. We have a very beautiful green campus, with a swimming pool and jogging ground. I try to use these facilities to keep my body fit.

I am also a melophile of Rabindra Sangeet (songs written by Rabindranath Tagore), and I enjoy this whenever I get some leisure time.

Q. Thank you for your comments.

Bijnan: Thank you very much for giving me an opportunity to share my views.

JEFF PETERS

Q. How did your education and early experiences lead to your initial and continuing interest in the control field?

Jeff: Growing up, my dad owned and operated a small sheet metal fabrication shop that did custom metal work for various applications, mostly without the use of computer numerical control or other computerized machining equipment. As such, I got to see firsthand how hard my dad worked and just how much skill and precision were needed to complete the job. As I grew older and began studying control, I became fascinated by the fact that one could use tools from math and logic, two areas that interested me, to make it easier for people like my dad to complete their jobs. This was the catalyst for my initial interest in control, and it continued to develop as I explored how these same tools could be applied to various applications and autonomous systems.

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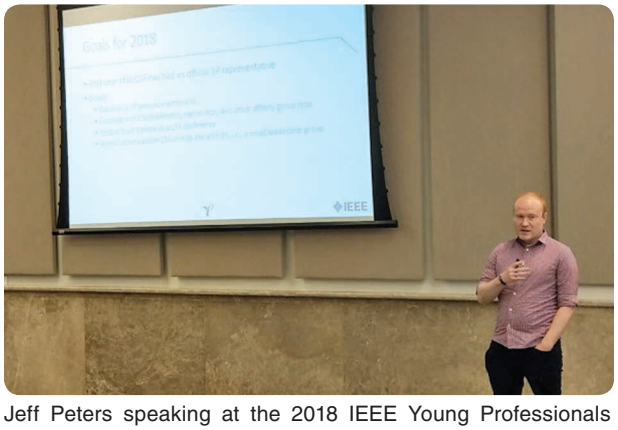
Jeff Peters

Q. What are some of your research interests?

Jeff: My research interests lie primarily in the development of algorithms and control policies for multiagent systems, such as systems of mobile vehicles or unmanned aerial vehicles. More specifically, I'm interested in developing strategies that would allow a single human user (or a few human users) to effectively manage a team of autonomous agents. This not only requires methods for coordinating autonomous agent behavior but also careful thought about how to leverage the strengths and weaknesses of both humans and robots in a single, tightly coupled, and collaborative framework. I also have broad interest in optimization, machine learning, and data analytics and how these tools can be leveraged within the same frameworks.

Q. What courses do you teach relating to control? Do you have a favorite course? How would you describe your teaching style?

Jeff: As a graduate student, I had the opportunity to teach two courses:



Jeff Peters speaking at the 2018 IEEE Young Professionals Global Meetup.

Jeff Peters in Dover, United Kingdom.