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Learning, Control and Hybrid Systems

Festschrift in honor of Bruce Allen Francis and Mathukumalli Vidyasagar on the occasion of their 50th birthdays

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Editors

Yutaka Yamamoto, PhD
Department of Applied Analysis and Complex Dynamical Systems
Graduate School of Informatics, Kyoto University, Kyoto 606-8501, Japan

Shinji Hara, PhD
Department of Computational Intelligence and Systems Science
Tokyo Institute of Technology, 4259 Nagatchuta-cho, Midori-ku,
Yokohama 226-8502, Japan

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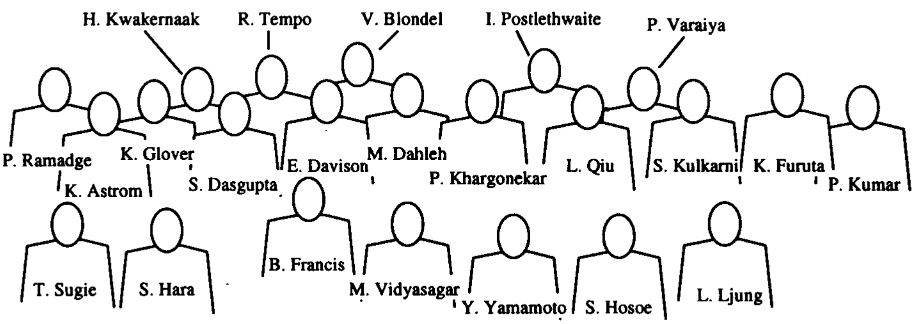
Dedicated to

Bruce Allen Francis and Mathukumalli Vidyasagar

on the occasion of their 50th birthdays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Preface

Two prominent control/system theorists Mathukumalli Vidyasagar and Bruce Allen Francis both turned 50 years of age in 1997, on September 29, and October 8, respectively, only about one week apart. To celebrate this memorable occasion, their friends got together at Bangalore (India) and had a workshop from January 4 through 8, 1998, under the same title of the present volume. This book grew out of this workshop.

Mathukumalli Vidyasagar was born in Guntur, Andhra Pradesh, India on September 29, 1947. He moved to the United States at the age of 13 along with his father (a renowned mathematician). He received the B.S., M.S., and Ph. D. degrees, all in Electrical Engineering, from the University of Wisconsin, in 1965, 1967, and 1969, respectively. Since then, he has taught at various universities in the U. S. and Canada, but at around the age of 40, he decided to return to his country. Since June 1989, he has been the Director of the Centre for Artificial Intelligence and Robotics (CAIR) in Bangalore, India, and has shown great leadership in guiding this institute. Among his honors in recognition of his research activities are the Distinguished Service Citation from his Alma Mater (The University of Wisconsin). He is also a Fellow of IEEE and the Third World Academy of Sciences as well as the Indian Academy of Sciences, the Indian National Science Academy and the Indian National Academy of Engineering.

He is the author or co-author of seven successful books (among them is the "Control System Synthesis" by MIT Press) and more than one hundred and twenty papers in archival journals. He is renowned for his fundamental contributions in nonlinear stability theory, robust control, especially, fractional representation approach, graph topology. In recent years, he has shown interest in various fields including robotics, artificial intelligence, neural networks, and learning theory.

Bruce Allen Francis was born in Toronto, Canada, on October 8, 1947. He obtained his B. A. Sc. and M. Eng. degrees in Mechanical Engineering and his Ph. D. degree in Electrical Engineering from the University of Toronto in 1969, 1970, and 1975, respectively. Since then, he has taught at various institutions, including the University of Cambridge and McGill University. He is presently a Professor in the ECE Department of the University of Toronto. He is a Fellow of the IEEE since 1988, and a co-recipient of two Outstanding Paper Awards for papers appearing in the IEEE Transactions on Automatic Control in 1984 and 1990, and also a co-recipient (with Doyle, Glover, and Khargonekar) of the 1991 IEEE W.R.G. Baker Prize Award (for the most outstanding paper reporting original work in the IEEE Transactions, Journals, Magazines, and Proceedings).

His contributions in linear systems, robust control, sampled-data systems are very fundamental. Of particular importance are the derivation of the internal model principle for servomechanism control, derivation of the first general solution to the H_∞ control problem, and sampled-data H^∞ control. He is recently interested in widening the scope of application of control theory; this attempt includes his new approach to digital signal processing. He has authored three books; among them is the very successful "A Course in H_∞ Control Theory" from Springer-Verlag, which greatly popularized this theory.

Bruce and Sagar had lots of crossover in between. It is less known that Bruce first started his career as Sagar's Ph. D. student in 1971-2, and later they were colleagues at University of Waterloo during 1982-4. Needless to say, they have several joint papers together.

On the personal sides of the editors, it has been always pleasure meeting and discussing with Bruce and Sagar. We are sure that the participants and the authors of this volume will fully agree. We would like to indulge ourselves a little in recalling some past experiences on our personal acquaintances.

Yamamoto (abbr. YY hereafter) got acquainted with Sagar in 1981 when he was visiting Japan as a JSPS fellow. On one day he gave Sagar and his wife Shakunthala a round-trip ride between Kyoto and Osaka Universities when Sagar had to give a lecture at Osaka. That was when YY got to learn about the graph topology and its relation with fractional representations. Since then Sagar visited Japan several times; also, Hara (abbr. SH hereafter) had a one-year visit with Sagar in 1988. Through candid conversations SH introduced Sagar to learning Japanese, which turned out to be quite a hobby for Sagar later. In 1994, Sagar again visited Tokyo Institute of Technology as a Nippon-Steel Visiting Chair Professor. He gave several lectures in Japanese, with Japanese LaTeX slides. It was a lot of fun for YY to help Sagar with Japanese through very late night telephone conversations. (Unfortunately, his wife and daughter had to return to India earlier than planned, and he was left alone as a single in Tokyo. As a result, he would often come back to office late at night to work.)

During his visit to Canada (in 1989), SH also had a visit with Bruce, and that was his first exposure to sampled-data H^∞ control. Much earlier in 1981, Bruce had attended YY's paper presentation in IFAC World Congress in Kyoto, but this somehow did not turn into a close exchange of opinions. Later around 1984, SH and YY started their joint work on repetitive control, and the crucial factor here is a generalization to an infinite-dimensional context of the internal model principle—one of the key contributions in servomechanism control by Bruce (along with M. Wonham). Then much later in summer of 1989, Bruce visited Japan as a JSPS fellow, and he gave a series of lectures on sampled-data control theory. At that time, YY was also contemplating a new model for sampled-data systems, and the series of lectures that Bruce gave greatly stimulated him. It soon (in the summer) culminated into a new function space model which is now also known under the name of lifting.

In commemorating their superb contributions to system and control theory, the primary objective of the Bangalore workshop, entitled "Learning, Control and Hybrid Systems" was to enlighten the current state of the art and future directions in systems and control theory. Reflecting their wide range of contributions and the variety of attendees, the contributions include many research areas. This volume is herewith dedicated to them.

The present volume consists of four parts, each entitled: "Learning and Computational Issues," "Hybrid Systems," "Modeling, Identification and Estimation," and "Robust Control." Each part reflects the current status of the field or a new approach in system theory.

The first part contains five papers related to learning and computational issues. The recent advances in robust control re-united various methods in operations research and control theory. Varied design and analysis problems are re-formulated as numerical optimization problems. On the other hand, it is gradually recognized that many control problems are computationally hard. For example, the computation of the structured singular value (μ analysis) is known to be NP hard. While this does not necessarily mean that such problems are genuinely intractable problems, it also shows that they may be computationally intractable if one imposes naive solutions. One possible direction is to relax the requirement of a "hard bound" in performance or in computational procedure. The first paper by Sagar himself discusses this issue based on a property in statistical learning theory, i.e., uniform convergence of empirical means (UCEM) property. He shows that the UCEM property assures the existence of an efficient randomized algorithm and proves that it holds in several robust control problems using recent results in VC-dimension theory. The second paper by Khargonekar and Tikku is focused on concrete randomized algorithms for robust stability analysis and robust controller synthesis. They provide several numerical examples to show the effectiveness of the proposed randomized algorithms. Blondel and Tsitsiklis investigate the decidability and the NP-hardness of stability and null-controllability tests for three classes of discrete-time nonlinear systems. The fourth paper by Hara and Yamada discusses the computational complexity of a fairly general class of non-convex optimization problems, named Matrix Product Eigenvalue Problem (MPEP), in robust control synthesis. Then the paper by Georgiou and Tannenbaum introduces a new technique using the Groebner bases for the computation of switching surfaces in time optimal control. The method is expected to be effective given the complexity of the task.

Part B is centered around hybrid systems. Needless to say, control systems are usually placed in hybrid environments. Purely linear control system structures hardly occur in practice. They are usually placed under higher-level logic controls, switching mechanisms that are to take care of some unpredicted operating condition changes, etc. Controllers are also implemented in a sampled-data setting, where the mixture of continuous and discrete timings occur simultaneously. In the past, control theorists often ignored such a hybrid nature of control environments, but it has been gradually recognized that absorbing such hybrid natures into the framework of control is a vital factor in making the control engineering more amenable to reality. This part collects varied contributions in such attempts.

The first paper by Bruce himself addresses the issue of sampled-data/digital control and gives an overview of his new approach toward digital signal processing via this new theory. The emphasis here is on the capability that the new, modern sampled-data theory, initiated by his leadership in the late 80's, can handle the aliasing problem in a unified, optimization framework, such as the H^∞ control theory. The second paper by Yamamoto and Khargonekar discusses basically the same issue; the emphasis is placed more on the continuous-time behavior. Various design examples are illustrated to show the superiority of the modern H^∞ design. The paper by Dasgupta also discusses a problem of digital signal processing. He shows a solution to the minimization of quantization error by bit allocation in biorthogonal, maximally decimated uniform filter banks. The fourth paper in this part by Hocherman-Frommer, Kulkarni and Ramadge discusses switching control. The switching occurs based on output prediction errors, and sufficient conditions are derived under which the closed-loop system remains exponentially stable while maintaining good tracking properties. The contribution by Åström discusses a task level control by taking an inverted pendulum as an laboratory example. There can be many different tasks that can be imposed on an inverted pendulum, for example, swing-up of the pendulum, catching a swinging pendulum, etc. The paper discusses various issues in such control problems. The next paper by Furuta and Pan addresses the issue of the variable structure control of sampled-data systems, and the proposed discrete-time controller quadratically stabilizes the system. Yurkovich's paper gives a perspective on fuzzy control. The role of heuristics, need of high-level decisions, etc. are examined from the viewpoint of conventional control engineers.

Part C includes various contributions related to modeling. The importance of modeling adequate for control cannot be over-emphasized, especially now robust control theory has reached some maturity. The first paper by Ljung discusses various issues in identification for control, e.g., frequency ranges on which the model should fit, iterative design, model validation etc. It gives a compact overview as well as directions for future study. The second paper by Dahleh discusses the identification of complex systems; here the issue is choosing a finitely parametrized family of models instead of just one. The third paper by Bai, Tempo and Ye discusses the issue of system parameter estimation, but from the new viewpoint of the analytic center approach, reflecting the recent advances in interior point algorithms. The estimation problem can be formulated as a convex programming problem, and the authors propose the method of analytic center. In contrast, the paper by Kulkarni and Posner give a nonparametric output prediction problem for nonlinear, discrete-time systems. Under some mild assumptions, the algorithm is shown to converge. Once we obtained a model, its simplification is often of crucial interest, for while the model should be accurate enough to capture the essential features of a plant, it should also be simple enough to be effective for system design. The paper by Glover, Goddard and Chu surveys recent results in the model reduction for uncertain, parameter-varying nonlinear systems. Various methods based on balancing are examined. The paper by Mitter and Sahai is focused on the role of the notion of information in control. They review Witsenhausen's notions of information pattern and show that there exists a family of nonlinear quantizing control laws which can be superior to the best linear one. The final paper in this part by Yanagisawa and Kimura addresses a control problem in a quantum mechanical context. In minimizing a variance, the authors are interestingly led to a least square optimal control problem.

Robust control has been the key word in control theory for at least the past decade and a half. Part D contains eight contributions in this subject in varied aspects—theory and applications.

The papers by Kwakernaak and Hosoe both deal with H^∞ control, the former dealing with descriptor systems, and the latter with emphasis on a unified approach. Spectral factorizations play crucial roles in both papers. The paper by Postlethwaite, Smerlas and Walker shows the first H^∞ controller that worked on a real helicopter. The difficulties encountered are in high levels of uncertainty and cross-axes coupling, but the test shows impressive results. The paper by Chen and Sugie proposes new parameter dependent multipliers to yield less conservative bounds for μ (the structured singular value). The next paper by Davison discusses the recent issues on the concern of the robustness of optimal controller in the presence of uncertainty both in the plant and the controller. The paper shows that a certain design approach can indeed possess such robustness. The next paper by Qiu and Chen discusses the time-domain performance limitations of feedback control—as opposed to usual frequency domain results. The paper by Honda, Suzuki and Sakamoto introduces quadratic constraints and discusses loopshaping in the open loop. The final paper by Gorbet, Morris and Wang deals with the problem of hysteresis. This nonlinear behavior appears in many devices such as shape memory alloys. The authors employ the Preisach model, and show that it can be placed in the standard dynamical system framework.

The papers are based on the presentations given in the Bangalore workshop, but we have also included some papers of the authors who could not attend the workshop for a variety of reasons. On the other hand, we could not unfortunately include some papers that were presented at the workshop.

Acknowledgments

The workshop was intense, academic, pleasant and very successful, both from scientific and social points of view. It pointed to various new directions, and serious exchanges of views and ideas were observed throughout. We are grateful to CAIR for undertaking the effort of organizing the workshop and for the smooth operation of the meeting. We thank Hideaki Ishii for the help in formatting the texts, and also Nicholas Pinfield and Alison Picken at Springer-Verlag for their valuable editorial assistance.

Yutaka Yamamoto
Shinji Hara
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