Preface

Life has many surprises. One of the best surprises is meeting a caring mentor, an encouraging collaborator, or an enthusiastic friend. This volume is a tribute to Professor Michael K. Sain, who is such a teacher, colleague, and friend. On the beautiful fall day of October 27, 2007, friends, families, colleagues, and former students gathered at a workshop held in Notre Dame, Indiana. This workshop brought together many people whose lives have been touched by Mike to celebrate his milestone 70th birthday, and to congratulate him on his contributions in the fields of systems, circuits, and control.

Mike was born on March 22, 1937, in St. Louis, Missouri. After obtaining his B.S.E.E. and M.S.E.E. at St. Louis University, he went on to study at the University of Illinois at Urbana-Champaign for his doctoral degree. With his Ph.D. degree complete, he came to the University of Notre Dame in 1965 as an assistant professor. He became an associate professor in 1968, a full professor in 1972, and the Frank M. Freimann Chair in Electrical Engineering in 1982. He has remained at and loved the University of Notre Dame for over 40 years. Mike also held a number of consulting jobs throughout his career. Most notably, he consulted with the Energy Controls Division of Allied-Bendix Aerospace from 1976 to 1988 and the North American Operations branch of the Research and Development Laboratory of General Motors Corporation for a decade, 1984–1994.

Mike's research interests have been wide and varied. He worked on statistical control and game theory with a focus on the use of cumulants, system theory on semirings, generalized pole and zero techniques, nonlinear multivariable feedback control with tensors, structural control for buildings and bridges subject to high winds and earthquakes, jet engine gas turbine control, algebraic systems theory, and generalization of H_∞ control.

Mike is a pioneer in statistical control theory, which generalizes traditional linear-quadratic-Gaussian control by optimizing with respect to any of the cost cumulants instead of just the mean. For over 30 years, Mike and his students have contributed to the development of minimal cost variance control, kth cumulant control, and statistical game theory. In statistical game theory, the statistical paradigm generalized mixed H_2/H_∞ control and stochastic H_∞ control concepts. Although there is more

work to be done in this area, Mike has pioneered a promising new stochastic optimal control method.

Another major contribution of Mike's research is in the field of algebraic systems theory, expanding the algebraic system-theoretic concepts of poles and zeros of a linear system. Mike and his collaborators also researched a module-theoretic approach to zeros of a linear system and the application of these ideas to inverse systems. Mike's 1981 monograph *Introduction to Algebraic Systems Theory* bridged the gap between systems theory and algebraic theory and is considered a definitive introduction to algebraic systems theory.

More recently, Mike has applied concepts from feedback control theory to model Catholic moral teachings and decision making, showing that analogous structures exist in the two fields, and that one can construct a framework to support selection of "good" outcomes and rejection of what is "not good."

Mike has also been a valuable resource to the Institute of Electrical and Electronics Engineers (IEEE). In particular, he was the founding editor-in-chief of the flagship *Circuits and Systems Magazine*. Mike, with the support of then IEEE Circuits and Systems Society president Rui De Figueiredo, changed the *IEEE Circuits and Systems Society Newsletter* into the *Circuits and Systems Magazine*, a highly regarded magazine within the IEEE. Mike was also the editor-in-chief of the journal of record in the field of control systems, the *IEEE Transactions on Automatic Control*. He also served on numerous award committees, including the IEEE Award Board, where he chaired the Baker Prize Committee which annually determines the best publication from among all those in the transactions and journals of the IEEE. During his 42 years of service, he has received numerous awards and honors including the IEEE Centennial Medal, IEEE Circuits and Systems Society Golden Jubilee Medal, IEEE Fellow, and University of Notre Dame President's Award.

Perhaps more importantly, Mike is widely recognized by his peers and students as an outstanding educator, and he has received several teaching awards for his excellent pedagogy. He has directed over 47 theses and dissertations, 19 of which are doctoral dissertations, and his students have become leaders in academic research, teaching, and administration, and in industry and government.

This *Festschrift* volume is divided into four parts: statistical control theory, algebraic systems theory, dynamic systems characteristics, and engineering education. The statistical control theory part begins with a survey. Statistical control is a generalization of Kalman's linear-quadratic-Gaussian regulator. Here, we view the optimal cost function as a random variable and optimize the cost cumulants. The current state of research is discussed in the first chapter. In the second chapter, Cumulant Control Systems: The Cost-Variance, Discrete-Time Case, the authors address the second cumulant optimization for a discrete-time system. In this digital world, this is an important addition to statistical control theory. The third chapter, by Pham, discusses statistical control for a system with integral feedback, and extends the statistical control idea to both regulation and tracking problems. The fourth chapter uses a statistical control paradigm for decision making, using multi-player game theory. The final chapter of Part I deals with multi-objective cumulant control. Here the cumulant idea is applied to mixed H_2/H_∞ control. Instead of optimizing the mean in the H_2

cost function, the authors optimize the variance while constraining the system's H_∞ norm. Interestingly, this idea generalizes stochastic H_∞ control.

The second part of the book is dedicated to algebraic systems theory. Its first chapter describes a new system theory for linear time-invariant systems with coefficients in a semiring motivated by applications in communication networks, manufacturing systems, and queueing systems. In addition to revealing realization issues of systems over semirings, this theory connects geometric control with the frequency domain and provides methods to compute invariant sets associated with decoupling. The second chapter, by Schrader and Wyman, discusses the module-theoretic approach to zeros and poles of a linear multivariable system. By examining the intuition that the zeros of a linear system should become the poles of its inverse system, this chapter emphasizes Mike's contributions to this body of knowledge. The main result provides a complete understanding of the connection between all poles and zeros of a transfer function matrix, including those at infinity and those resulting from singularities. The final chapter of this section, by Conte and Perdon, presents the notion of zeros for linear time-delay systems by generalizing the algebraic notion of a zero module. Additional control problems such as inversion and tracking are also addressed using this framework.

The third part starts with the overview of stability results for discontinuous hybrid dynamical systems. Michel and Hou show that if the hypotheses of a classical Lyapunov stability and boundedness result are satisfied for a given Lyapunov function, then the hypotheses of the corresponding stability and boundedness result for discontinuous dynamical systems are also satisfied for the same Lyapunov function. They also show that the converse is not true in general. The second chapter solves complex systems using a neural network structure. In particular, it discusses two algorithms, based on a biologically inspired structure, in solving for an optimal state feedback controller. The third chapter tackles the characterization and calculation of approximate decentralized fixed modes. The fourth chapter is concerned with a communications system, wherein Lee and de Figueiredo discuss two approaches to mitigate adverse effects due to the high peak-to-average power ratio in orthogonal frequency division multiplexing systems. Then Polendo *et al.* discuss constructive techniques for stabilization of nonlinear systems with uncertainties and limited information. The final chapter of this part presents a systematic method for deriving and realizing nonlinear controllers and nonlinear closed-loop systems using Volterra control synthesis.

Mike has been a lifelong mentor and teacher to many students. So, appropriately, we have chosen two important subjects in education for this volume. One important topic is the issue of the first professional degree in engineering. In this context, Dorato argues that the first professional degree in engineering should be the Master of Engineering degree rather than the bachelor's degree. In order to maintain America's competitiveness, advances in engineering education are prerequisite. This chapter should generate some insight into the question of what constitutes a true engineering education. A relatively new interest of Mike has been the research of the relationship between theology and engineering. In this research he has been collaborating with his daughter at St. Thomas University. Thus, it is appropriate to end this volume with a chapter about theology and engineering, authored by Barbara Sain.

There she answers the question: What does the discipline of engineering have to do with the life of faith? It is interesting and insightful to see models of the will in block diagrams!

Religion is an important part of Mike's life. He is a devoted Catholic with a great love and devotion for the Virgin Mary. He attends daily Mass and has visited Medjugorje in Bosnia-Herzegovina four times. Perhaps this is why his view on life is larger than just research or teaching. We would like to end this preface with a prayer—the same prayer that begins all Mike's classes—because this is another commencement for Mike.

Our Father, Who art in heaven
Hallowed be Thy Name;
Thy kingdom come,
Thy will be done,
on earth as it is in heaven.
Give us this day our daily bread,
and forgive us our trespasses,
as we forgive those who trespass against us;
and lead us not into temptation,
but deliver us from evil. Amen.

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