the design variable. Both algorithms relay on the quality of the parameter estimation of the assumed ARX model structure. Also included are versions of the state-space representation of these two controller designs, which serves as a platform to establish the relationship with the state-space control approach and the predictive control approach.

The book addresses many issues related to identification and control of structural systems, and serves as a good textbook in this field. As many classroom textbooks, the in-depth focus is traded for a broader scope of the topics included. The coverage of the individual topics is sufficiently in-depth covered for classroom work, and causes enough curiosity by the reader to study the mentioned topics further by using the listed references at the end of each chapter. The book's scope and coverage fills a void in the area it set out to do in a very readable and instructional way.

MARCO P. SCHOEN
College of Engineering
Idaho State University
Pocatello, ID 83209-8060, U.S.A.
E-mail: schomarc@isu.edu

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NONLINEAR AND ROBUST CONTROL OF PDE SYSTEMS—METHODS AND APPLICATIONS TO TRANSPORT-REACTION PROCESSES, Panagiotis D. Christofides, Birkhauser, Boston, MA, USA, 2001, 248pp.

The control and estimation problems for distributed parameter systems in the context of chemical processes were first addressed in the well-recognized book by Ray [1]. Many prominent chemical processes exhibit spatial variations of the states and there a number of processes where one is interested in maintaining a desired spatial profile for key variables in the presence of disturbances. The control input can enter through the domain equations or may appear in the boundary conditions. The problem is exacerbated by nonlinear dynamics that typically arise from coupled transport and reaction phenomena. Early attempts to solve such problems provided local linear control designs that are based on finite-dimensional approximations of the infinite dimensional system, often using orthogonal collocation as the method of choice for discretizing the spatial derivatives. Naturally, such approximate solutions are undesirable as they offer limited insight into the complexities of processes described by nonlinear PDEs. The book by Christofides recounts the historical evolution of this field (Chapter 1) and provides an excellent account of where the field is today. Notably, with the maturation of differential geometric control theory, a considerable array of machinery became available to design controllers for nonlinear lumped parameter systems in the presence of modelling uncertainties [2]. By identifying and deftly exploiting the key spectral features of the classes of hyperbolic and parabolic PDE systems, Christofides supplies the missing link between such machinery and distributed parameter systems. It should be noted that the book focuses on quasi-linear hyperbolic and parabolic PDE systems whose solutions are unique and smooth. Furthermore, the problem formulation is confined to bounded manipulated and measured variables that effectively excludes problems where there is actuation or sensing at the boundaries.

The first chapter discusses the origins of the problem, provides two motivating examples and explains the organization of the book. It is notable that the motivating examples are chosen from non-traditional process systems, one describing an aerosol reactor and the other a rapid thermal chemical vapour deposition (RTCVD) process. Each chapter that follows also offers an illustrative example that walks the reader through the derivation and the implementation of the feedback control laws.

The second chapter focuses on hyperbolic PDE systems for which modal decomposition is an ineffective strategy for simplification. Moreover, the system dynamics is sensitive to the sensor/actuator placement, thus requiring a formulation that explicitly considers the infinite dimensional nature of the problem. This chapter presents a brief review of the theoretical foundations for these systems and introduces a key concept, the characteristic index, which is a generalization of the relative order for nonlinear finite dimensional systems [2] and allows for the characterization of the spatiotemporal interactions between the outputs and the inputs. Using the characteristic index, first, a feedback controller is designed for the linear PDE system and then extended to the quasi-linear PDE system. The controller takes advantage of the inverse-based control design concepts and results in a linear input–output response for the closed-loop system. Then, it is shown that for exponential stability of the closed-loop system, a key requirement is stable open-loop zero dynamics. The chapter concludes by establishing the method to construct state-observers to facilitate output feedback control.

The next chapter (Chapter 3), still on hyperbolic PDE systems, takes on the effect of model-plant mismatch. The aim is to design robust controllers based on Lyapunov's direct method that can explicitly account for unmodelled dynamics and time-varying uncertain variables. The key result (Theorem 3.2) gives a solution of the uncertainty decoupling problem and Theorem 3.3 (all proofs are placed in the Appendixes to maintain continuity) establishes the robust control result for a broader class of systems, where the restriction on the characteristic index is relaxed, at the expense of a weaker performance requirement. An interesting development in this chapter is the introduction of a two-time scale decomposition that provides the setting for showing robust stability with respect to unmodelled dynamics.

The fourth chapter is devoted to parabolic PDE systems. The control design for these systems takes advantage of the separation in the eigenspectrum (finite-dimensional slow modes and infinite dimensional fast and stable modes) and is based on the slow finite dimensional complement. First, the eigenvalue problem is discussed with several examples highlighting the key observations. Then, the Galerkin's method is reviewed as a means to derive an approximate finite-dimensional system model. Using the singular perturbation arguments, it is shown that the ODE system obtained thusly does not permit an accurate estimation of the degree of approximation obtained. To facilitate the construction of finite-dimensional ODE systems, whose solutions can be arbitrarily close to the ones of the infinite dimensional system, a strategy based on approximate inertial manifolds (AIMs) is proposed. Once a nonlinear ODE system is obtained, the main result of this section is to derive a finite-dimensional output feedback controller that guarantees stability of the ODE system and exponentially stabilizes the PDE system.

As before, the following chapter (Chapter 5), still on the parabolic PDE systems, deals with the extension to the robust control design case. The ODE system obtained through the methods discussed in Chapter 4 is used to synthesize the robust feedback law. First, by assuming a nonlinear time-varying bounding function that can quantify the magnitude of the uncertainty, Theorem 5.1 offers a control law that can guarantee a certain level of uncertainty attenuation. Another key assumption in this theorem is the existence of slow/fast modes and due to their dependence on physical system parameters, the separation may not always be sufficiently large, thus limiting the degree of attenuation. The attention is turned next to AIMs to explore ways to improve the uncertainty attenuation. Theorem 5.2 allows for a precise characterization of the level of uncertainty attenuation that is considered to be satisfactory for most practical applications.

The sixth chapter is one of the key contributions of this book. Considering the problem of process systems where the spatial domain may be time-dependent (e.g. growing single crystals of Si for semiconductor applications), Christofides reformulates the control problem for parabolic

PDE systems to include moving boundaries. In this formulation, the PDE system is expressed in the Hilbert space as an evolution equation where the differential operator is time-varying. Again, the dynamics of the infinite-dimensional system is decomposed into slow (finite) and fast (infinite) modes (there is a natural extension to PDE systems with moving boundaries) and the problem is solved analogous to the methodology introduced in Chapter 4.

The seventh chapter presents two detailed case studies. This is an extremely valuable chapter as it not only clearly illustrates the various methodologies introduced earlier in the book but also fully documents the application of nonlinear control theory to two novel process systems.

This book caters to a specialized readership with some knowledge of PDE systems as well as nonlinear control, specifically, the differential geometric control theory. It would be a valuable book for researchers who are interested in learning the state-of-the-art in control of PDE systems, and also for those practitioners with specialized applications that would benefit from the problem formulation presented herein. The book fills a clear niche in the control of PDE systems, and establishes a benchmark with which the future control methodologies will be compared. It certainly will be one of the highly referenced books in this subject and I can confidently recommend it.

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Ahmet Palazoglu
Department of Chemical Engineering and Materials Science University of California, One Shields Avenue, Davis, CA 95616, USA
E-mail: anpalazoglu@ucdavis.edu

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