Preface

This is a book on robust and optimal control of linear, time-invariant systems.

The human being always seeks better results in all activities, and this desire pushes the advance of science and technology. This happens in the control systems and control engineering area as well. It is desirable to develop a control strategy, a controller, for a dynamic system under consideration, to satisfy all possible constraints and to optimize a certain cost function which reflects the design objectives. This is so-called an optimal control problem. Such problems can be traced back to as early as the seventeenth century, in the Brachistochrone curve problem raised by Johann Bernoulli. Solution approaches towards such problems include the classical Calculus of Variations, Pontryagin's Maximum Principle, Dynamic Programming, (Differential) Game Theory, and Nonsmooth Optimization. These procedures are complicated, and solutions do not always exist. Fortunately, for linear time-invariant (LTI) systems, many cases would have satisfactory results, and this book presents a powerful approach which is also easy to understand, for electrical engineers in particular, we hope.

On the other hand, robustness is another vitally important issue in control systems design. A successfully designed automatic control system should be always able to maintain stability and an acceptable performance level despite uncertainties in system dynamics and/or in the operation environment to a certain degree, while such uncertainties inevitably exist in any real-world control system. In the late 1970s and early 1980s with the pioneering work by Zames [8] and Zames and Francis [9], a theoretic development, now known as the H_∞ optimal control theory, was taking shape. Robust controllers for LTI systems can be found by solving corresponding optimization problems. Robustness is thus achieved by designing a controller which attains certain optimality of the closed-loop system. The H_∞ and related optimization approaches are well developed and elegant. They provide systematic design procedures, in particular, for multi-input, multi-output linear systems.

There have been a number of books on this subject. Some books are on the underlying theories and the derivation of solution formulae [1, 3, 5, 7, 10]. Others are more on design methodologies, application of such theories, and implementation software [2, 6]. Naturally, a question arises, "Do we need another book on this subject?"

It seems satisfactory that practicing control engineers can use available solution formulae and software routines to work out robust and optimal controllers for given design problems, when they know well the underlying control systems and design specifications. However, are we happy with such designed controllers without knowing exactly how the formulae are derived and on what grounds the solution procedures are based? As control engineers, are we confident enough to implement such designed controllers? Answers to above queries might be obvious, and there are sources for us to know the theories of design approaches, as pointed out earlier. The problem is that the theory behind the state-space approaches presented in [10] and other books is very mathematically oriented and difficult for engineers, and students as well, to understand. Hence, is it possible to present the robust and optimal control theory for LTI systems in a way such that engineers and students can follow and grasp the essence of the solution approach? This motivated the research and writing of the present book.

This book presents an alternative approach to find a robust controller via optimization. This approach is based on the chain scattering decomposition (CSD), initiated by Professor Hidenori Kimura [4] and references therein who also named this as chain scattering description. CSD uses the configuration of two-port circuits which is a fundamental ingredient of electrical engineering and is familiar to all electrical engineers and students with basic electrical engineering knowledge. It is shown in the book that (sub)optimal H_∞, H_2 as well as stabilizing controllers can be synthesized following the CSD approach. The book starts from the well-know linear fractional transformation (LFT), in which a control design problem can easily be formulated, and then converts LFT into CSD format. From the CSD formulation, the desired controller can be directly derived by using the framework proposed in the book in an intuitive and convenient way. The results are complete and valid for general system settings. The derivation of solution formulae is straightforward and uses no mathematics beyond linear algebra. It is hoped that readers may obtain insight from this robust and optimal controller synthesis approach, rather being bewildered in a mathematics maze.

The prerequisites for reading this book are classical control and state variable control courses at undergraduate level as well as elementary knowledge of linear algebra and electrical circuits. This book is intended to be used as a textbook for an introductory graduate course or for senior undergraduate course. It is also our intention to prepare this book for control engineers training courses on robust and optimal control systems design for linear time-invariant systems. With the above consideration in mind, we use plenty of simple yet illustrative worked examples throughout the book to help readers to understand the concepts and to see how the theory develops. Where appropriate, *MATLAB* codes for the examples are also included for readers to verify the results and to try on their own problems. Most chapters are followed with exercises for readers to digest the contents covered in the chapter. To further demonstrate the proposed approaches, in the last chapter, an application case study is presented which shows wider usage of the framework.

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