Preface

In many practical applications we deal with a wide class of dynamical systems that are comprised of a family of continuous-time or discrete-time subsystems and a rule orchestrating the switching between the subsystems. This class of systems is frequently called *switched system*. Switched linear systems provide a framework that bridges the linear systems and the complex and/or uncertain systems. The motivation for investigating this class of systems is twofold: first, it has an inherent multi-modal behavior in the sense that several dynamical subsystems are required to describe their behavior, which might depend on various environmental factors. Second, the methods of intelligent control systems are based on the idea of switching between different controllers. Looked at in this light, switched systems provide an integral framework to deal with complex system behaviors such as chaos and multiple limit cycles and gain more insights into powerful tools such as intelligent control, adaptive control, and robust control. Switched systems have been investigated for a long time in the control and systems literature and have increasingly attracted more attention for the past three decades. The number of journal articles, books, and conference papers have grown exponentially and a number of fundamental concepts and powerful tools have been developed. It has been pointed out that switched systems have been studied from various viewpoints. One viewpoint is that the switching signal is an exogenous variable, and then the problem is to investigate whether there exists a switching signal such that the switched system has the desired performance including stability, certain disturbance attenuation level, and the like. Another viewpoint is that the switching signal is available to system designers and thus it may be used for control purposes. This book aims at integrating the main issues of switched systems in a systematic way.

On the contrary, the existence of transfer phenomena, including material, energy, and information, is an integral part of several physical and man-made systems. In turn, this gives rise to delay element and, consequently, the overall system representation would be the delay differential equations (DDEs) as opposed to the conventional ordinary differential equations (ODEs). Over the years, it is recorded that DDEs are used in modeling other phenomena arising in different fields, including biosciences (heredity in population dynamics), chemistry (behaviors in chemical kinetics), economics (dynamics of business cycles), engineering (water quality, hot and cold mills, vibration in cutting machines), to name a few. Time-delay systems
(TDs) have a long-standing history, and early treatment of DDEs dates back to the work of Bernoulli and Condorcet. The development of mathematical theory for TDs however started in the second half of the 20th century by the pioneering work of Myshkis, Krasovakii, Halanay, and Pinney in the frequency domain and Bellman, Cooke, and Hale in the time domain. From a control systems standpoint, delays give rise to stabilizing/destabilizing effects depending on the situation under consideration. By now it is fair to say the fundamental results of the theory of functional differential equations (FDEs), as equivalent to DDEs), are well known and well understood. However, there are increasing number of applications involving large-scale systems that exhibit the delay (transport, propagation, communication, decision) as a crucial parameter in the control analysis and design methods. Recent approaches in robust control opened interesting perspectives and issues in dealing with delays in dynamical systems, where delays are eventually treated as uncertainty.

Since most of the time delays have a crucial impact on the plant performance, the employment of FDEs rather than ODEs in the modeling effort becomes the rule, not the exception. Putting them together, a new class of system configuration readily emerges, which, from now onward, we call switched time-delay systems (STDS). This class possesses the main ingredients of multi-modes of operation, nominally inherent time-delay model and parametric uncertainties and external disturbances. Indeed, this class reflects several important features on the performance analysis and control design and emphasizes the existence of a hybrid system: state-space delay dynamics and switching dynamics.

There are numerous applications that can be cast in the framework of such STDS. Examples include, but not limited to, water quality control, electric power systems, productive manufacturing systems, and cold steel rolling mills. For obvious reasons, STDS can be best represented in the time domain by a hybrid state-space formalism the major part of which is a state-space hereditary model and a switching model forming the remaining part.

Recently, there has been considerable research interest in stability analysis and control design of STDS and satisfactory results have been obtained in the literature. While most of these excellent publications are for specialists and researchers in the field, so far there is no single book in the literature that presents a systematic and structured approach to the modeling, stability, and control of STDS. With this in mind, this book is about stability analysis and control design methodologies for such a new class of systems, STDs. Thus, the primary objective of the book is to present an introductory, yet comprehensive, treatment of STD systems by jointly combining the two fundamental attributes: the system dynamics possesses an inherent time delay and the system operational mode undergoes switching among different modes. Although each attribute has been examined individually in several texts, the integration of both attributes is quite unique and deserves special consideration.

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Switched Time-Delay Systems
Stability and Control
Mahmoud, M.S.
2010, XX, 433 p., Hardcover