

# Preface

Time delay appears in many physical processes due to the period of time it takes for the signals to transmit. Time-delay systems are largely encountered in modeling propagation phenomena, population dynamics, interconnected systems, supply chains, and systems controlled over communication networks. It is well known that time delay in control systems may lead to deterioration of the closed-loop performance or even destabilize the systems; therefore, specific analysis techniques and design methods are needed to be developed for control systems in the presence of time delay. The time-delay systems can be divided into linear time-delay systems and nonlinear time-delay systems. Recently, the stability analysis and control design of linear time-delay systems have been extensively studied with the popular tools—Lyapunov–Krasovskii functional method and Lyapunov–Razumikhin method. The stability and stabilization conditions can be transformed into solvable linear matrix inequalities (LMIs) with the help of Schur complement lemma.

Compared with linear time-delay systems, the study of nonlinear time-delay systems is more important for control theory and control applications, as most of practical systems have nonlinear dynamics and nonlinear uncertainties generally exist in practical engineering systems due to the modeling error and external disturbances. However, the analysis and synthesis of nonlinear time-delay systems are more difficult and challenging. The main reasons are as follows: (i) It is not easy to select Lyapunov functional for nonlinear time-delay systems. The Lyapunov functional for linear time-delay systems is generally chosen to be quadratic. But for nonlinear time-delay systems, we should construct Lyapunov functional based on the specific system structure, which increases the difficulties of stability analysis and control design. (ii) It is difficult to compensate for the time-delay effect while designing nonlinear controllers. For the control design of time-delay systems, we aim to design memoryless controllers independent of time delay, because the time delay is variable in practical systems and it is impossible to obtain the exact values of time delay. Hence, the controller design of nonlinear time-delay systems is different from that of the nonlinear systems free of time delay, as how to systematically design controllers to overcome the effect of time delay is very difficult.

This book is devoted to report the latest results on nonlinear time-delay control theory and applications, especially the robust control of time-delay systems with nonlinear uncertainties. This book collects some novel works related to commonly encountered nonlinear time-delay systems, such as the nonlinear systems in the form of high-order polynomial dynamics, systems with nonlinear input, and triangular nonlinear systems. Undoubtedly, the results in this book will enrich nonlinear system theory and time-delay system theory.

Our treatment is theoretically oriented, although some illustrative examples are included in this book. The reader is assumed to have some background in nonlinear systems and control. Although this book is primarily intended for students and practitioners of control theory, it is also a valuable reference for those in fields such as communication engineering and economics. Moreover, we believe that this book should be suitable for certain advanced courses or seminars.

In Chap. 1, the background and some descriptions of nonlinear time-delay system are provided.

Then, the rest of this book will be presented under the following parts:

Part I: The first part of this book is concerned with nonlinear time-delay systems with uncertainties in high-order polynomial form. In Chap. 2, based on the Lyapunov–Krasovskii functional and Razumikhin lemma, two classes of memoryless control design methods are proposed for single nonlinear time-delay system. In Chap. 3, the results are extended to a class of large-scale time-delay systems with interrelated  $N$  subsystems and the decentralized robust model reference adaptive controller is constructed.

Part II: The second part of this book focuses on some new results on nonlinear time-delay systems with general uncertainties. In Chap. 4, the decentralized adaptive state feedback control strategy is proposed for interconnected systems. In Chap. 5, the stabilization problem is investigated for a class of single uncertain mismatched systems with multiple time delays and a memoryless state feedback controller is constructed. In Chap. 6, the result is extended to a class of large-scale systems and the solution of the resulting closed-loop system can exponentially converge to a ball with adjustable radius. In Chap. 7, the control problem of nonlinear time-delay systems is studied via the T-S fuzzy approach.

Part III: The third part of this book is dedicated to nonlinear time-delay systems with two kinds of nonlinear inputs. In Chap. 8, the adaptive tracking control law for nonlinear time-delay system with non-symmetric dead-zone input is presented. In Chap. 9, based on T-S fuzzy approach, the decentralized networked control problem is investigated for large-scale time-delay systems with sector input.

Part IV: The last part of this book is devoted to controller design for nonlinear time-delay systems with triangular structure. In Chap. 10, the robust control problem is investigated for nonlinear time-delay systems with the form of triangular structure via Razumikhin lemma. In Chap. 11, the state feedback control problem is addressed for a class of nonlinear time-delay systems via Lyapunov–Krasovskii function. In Chap. 12, the robust output tracking control problem is investigated for a class of nonlinear time-delay systems with unmodeled dynamics. In Chap. 13, decentralized dynamic output feedback control problem is considered for a class of

nonlinear interconnected systems with time delay. In Chap. 14, the output feedback problem is investigated for a class of uncertain nonlinear time-delay systems with unknown control direction. In Chap. 15, dynamic output feedback tracking control strategy is presented for stochastic interconnected time-delay systems with prescribed performance requirement.

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