Book Reviews

Switched and Impulsive Systems: Analysis, Design, and Applications—Z. Li, Y. Soh, and C. Wen (Berlin, Germany: Springer-Verlag, 2005). *Reviewed by G. Zhai*

A *switched and impulsive system* is a collection of finite continuous variable systems (CVSs) combined with a discrete-event system (DES) governing the impulsive "switching" among them. Therefore, two kinds of dynamics, namely continuous dynamics and discrete events, coexist and interact in such systems. There are many practical systems which should reasonably be described as such systems. For examples, switched server systems, switched network flow, intelligent vehicle/highway systems, etc. Also, study of switched and impulsive systems leads to important applications in fields of mechanical systems, automotive industry, air traffic control, network control systems, quality of service in the Internet, and so on. As is well known, switched and impulsive systems (also abbreviated as *switched systems*) belong to a special class of *hybrid systems*, and there has been increasing interest in the analysis and design for hybrid systems in the last two decades. Due to the interdisciplinary nature, research attention in this relatively new but very active area has been growing among people with very diverse backgrounds including mathematicians, control engineers and computer scientists [4], [6], [3].

Since switched and impulsive systems have two aspects (continuous dynamics and discrete event) in their system structure, they make a bridge between control theory and computer science. At the present stage, researchers in control theory field usually adopt different modelling and analysis/design approach from those in computer science field. It is quite natural that researchers with a background and interest in continuous systems and control theory are concerned primarily with continuous dynamics, and thus, the discrete behavior, on the other hand, is usually regarded as a tool serving to achieve desired properties of the continuous dynamics, such as Lyapunov stability. The excellent book [2] has given precise introduction to the perspectives and results on stability analysis and controller design of switched and impulsive systems.

The book by Li *et al.* is on switched and impulsive systems, also taking the approach from Lyapunov stability theory. Compared with the existing books on this line, it aims to provide readers with a comprehensive coverage of switched and impulsive systems, together with their applications in various fileds.

The book is composed of ten chapters. Chapter 1 provides a number of examples to illustrate the concept and applications of switched and impulsive systems. The examples include a switched server system, an Internet router with multiple buffers, and the well-known Chua's Circuit. After precise definition and mathematical modelling of switched and impulsive systems, several practical examples are introduced: Synchronization of Lorenz systems via impulsive control, a crossroad scheduling system, a switched flow network, and a switched rate control scheme.

Chapter 2 formulates the state space of switched and impulsive systems and defines the stability of these systems with respect to an invariant set or an equilibrium. Less conservative stability conditions are established in the sense that Lyapunov function candidates are only required to be nonincreasing along a subsequence of the switchings and to be bounded by a continuous function along each CVS. The important concept of cycle is introduced here with some examples for the stability analysis. More precisely, a *cycle* is defined as a closed logical path in the switching sequence, where no discrete state appears more than once except for the first and the last discrete states. The key idea is that each cycle, instead of each CVS, is chosen as a unit for the stability analysis. If the redundancy of each cycle is removed, less conservative and easier-to-check conditions are obtained. It is noticed here that the idea of cycle analysis method is originally used in the information theory to improve the source coding gain [1].

Chapter 3 analyzes the stability of linear switched and impulsive systems. Three types of tools, namely multiple Lyapunov functions, matrix norms and matrix measures, are provided to measure the redundancy of each cycle. The cycle analysis method is applied to identify the nonincreasing subsequence and to construct the continuous functions to bound Lyapunov functions along each CVS. A decomposition method is proposed to study the stability of linear switched and impulsive systems, which are totally composed of unstable CVSs. The idea is to introduce a state transformation decomposing the original system into several lower dimensional systems which consist of both stable and unstable subsystems. Section 3.5 discusses stability of linear switched and impulsive systems with respect to invariant sets. It is noted here that more general discussion can also be found in [7] for stability analysis of switched systems with respect to invariant sets. The final section of this chapter deals with stabilization of linear switched systems where control input appears in each CVS and the switchings of CVSs are arbitrary. For other basic stability analysis and design problems of switched linear systems, [2] and [5] are also recommended.

Chapter 4 deals with the stability of nonlinear switched and impulsive systems. Three types of methods, namely multiple Lyapunov functions, linear approximation and generalized matrix measures, are presented to evaluate the redundancy of each cycle. It is interesting to notice that the multiple Lyapunov function method establishes the stability with respect to an invariant set, the linear approximation method establishes the stability with respect to the origin, and the generalized matrix measures method establishes the stability with respect to a given trajectory. Stabilization of nonlinear switched systems is also discussed in the framework of input-to-state stability and stabilizability.

In Chapter 5, less conservative conditions on stability of impulsive systems are first derived. These results are then used to study the stabilization and the synchronization of a class of chaotic systems via impulsive control. The synchronization is considered for Chua's Circuits and two Lorenz systems. In Chapter 6, the results obtained in Chapter 5 are used to design a chaos based secure communication system. Specifically, a switched and impulsive control strategy is designed for the synchronization of an encrypter and a decrypter. It is declared that by using the proposed strategy, the time necessary to synchronize two chaotic systems is minimized while the bound of the impulsive interval after the two systems are synchronized is maximized. Furthermore, with a larger impulsive interval, the transmission efficiency of the chaos-based secure communication systems can be improved significantly because less bandwidth is needed to transmit the synchronization impulses. Meanwhile, a concept of magnifying-glass and a novel switched sampling scheme are introduced to improve the security of the chaos cryptosystem. The proposed system can be applied to transmit text, speech, image files, and any digital binary data.

The reviewer is with the Department of Mechanical Engineering, Osaka Prefecture University, Osaka 599-8531, Japan (e-mail: zhai@me.osakafu-u.ac.jp).
Digital Object Identifier 10.1109/TAC.2006.884924

Chapter 7 provides an interesting and practical application of switched and impulsive systems. Specifically, the stability results are applied to study the scheduling problem of a class of switched server systems consisting of one server and multiple clients. A simple switching law of the server, *feedback cyclic control policy* (see also [3]), is proposed for the client/server systems. For simplicity, the focus is on the case where the arrival rate of each client is constant and known *a priori*. The proposed method is superior to one of the most popular methods, *deficit round robin (DRR)* method, in the sense that neither admission control nor resource reservation is required. The policies can be generalized to study scheduling problems of any switched flow network with a single server. In Chapter 8, the *feedback cyclic control policy* is first extended to the case where the arrival rates of the clients are not known in advance. The policy is then used to design a scheduling algorithm, called the *dual feedback cyclic control policy*, to provide a relative differentiated quality of service (QoS) in the current Internet. Meanwhile, a source adaption scheme and an adaptive media playout scheme are proposed using the switching control for the Internet with the relative differentiated QoS. Many precise examples with graphs are given to demonstrate the algorithm and the effectiveness. It is argued that with the proposed method, a very low cost solution can be provided to transmit video over the Internet.

Chapter 9 proposes a switched scalable video coding (SVC) scheme by using the methodoloy on switched and impulsive systems. The states of an SVC system include the given bit rate, resolution and frame rate. The control inputs are the motion information and the residual data to be coded. Usually, it is very difficult or even impossible to obtain a linear or nonlinear model for an SVC system. In this chapter, the switched control is proposed to improve the coding efficiency, which is composed of two tasks: The first is to determine the motion information and the residual information to be coded for each frame, and the second is to determine the switching point from one group of motion information and residual information to another group. Here, the focus is on the tradeoff between the motion information and the residual data, which is most crucial for video coding in an SVC system. The tradeoff is achieved by rate distortion optimization (RDO) with the utilization of a Lagrangian multiplier with a quantization parameter. The Lagrangian multiplier is adaptive to the customer composition in the scheme (thus called *customer-oriented scalable video coding scheme*). A novel coding scheme for the SVC, i.e., cross layer motion estimation/motion compensation (ME/MC) scheme, is also proposed with the introduction of a new criterion to the SNR scalability and the spatial scalability, respectively. A low-delay SVC scheme is also mentioned in the final section.

Chapter 10 describes several future directions and potential applications of switched and impulsive systems: global stabilization of nonlinear systems with abrupt change, control of light railway transfer (LRT) system, congestion control of LAN, next generation of video coding system, etc.

The book is written in depth, and all the topics are closely related to the basic problems in analysis and control of switched and impulsive systems. Furthermore, all the main results presented here are contributed originally by the authors and their collaborators. These results play an important role in the area of switched systems and switching control. Therefore, the reviewer recommends this book to all researchers who are interested in studying switched/hybrid systems and their applications. Control theorists and mathematicians will find that this book is a very comprehensive reference source.

Although many results are difficult to understand and the proofs/notations may not be easy to follow, the authors have made great efforts in the arrangement of the book so that the content is easier to follow. There are many insightful examples, figures and illustrations, and the authors have provided many references related to the book.

As can be seen in the description of the chapters, the authors have used much space for applications of switched and impulsive systems. The applications are wide, spreading in dynamical systems, chaotic communication systems, scheduling problems and video coding schemes. Therefore, researchers with various different backgrounds can find what they need and in the meanwhile may be motivated by descriptions for other areas. For the same reason, the reviewer believes that the book is equally valuable to practicing engineers.

References

[1] T. M. Cover and J. A. Thomas, *Elements of Information Theory*. New York: Wiley, 1991.

[2] D. Liberzon, *Switching in Systems and Control*. Boston, MA: Birkhäuser, 2003.

[3] A. S. Matveev and A. V. Savkin, *Qualitative Theory of Hybrid Dynamical Systems*. Boston: Birkhäuser, 2000.

[4] A. N. Michel, K. Wang, and B. Hu, *Qualitative Theory of Dynamical Systems*, 2nd ed. New York: Marcel Dekker, 2000.

[5] Z. Sun and S. S. Ge, *Switched Linear Systems: Control and Design*. New York: Springer-Verlag, 2005.

[6] A. van der Schaft and H. Schumacher, *An Introduction to Hybrid Dynamical Systems*. London, U.K.: Springer-Verlag, 2000.

[7] X. Xu and G. Zhai, "Practical stability and stabilization of hybrid and switched systems," *IEEE Trans. Autom. Control*, vol. 50, no. 11, pp. 1897–1903, Nov. 2005.