Studies in Systems, Decision and Control

Volume 356

The series "Studies in Systems, Decision and Control" (SSDC) covers both new developments and advances, as well as the state of the art, in the various areas of broadly perceived systems, decision making and control–quickly, up to date and with a high quality. The intent is to cover the theory, applications, and perspectives on the state of the art and future developments relevant to systems, decision making, control, complex processes and related areas, as embedded in the fields of engineering, computer science, physics, economics, social and life sciences, as well as the paradigms and methodologies behind them. The series contains monographs, textbooks, lecture notes and edited volumes in systems, decision making and control spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution and exposure which enable both a wide and rapid dissemination of research output.

Indexed by SCOPUS, DBLP, WTI Frankfurt eG, zbMATH, SCImago.

All books published in the series are submitted for consideration in Web of Science.

More information about this series at http://www.springer.com/series/13304

Dawei Shi · Yuan Huang · Junzheng Wang ·
Ling Shi

Event-Triggered Active Disturbance Rejection Control

Theory and Applications

Science Press
Beijing

Springer

Dawei Shi
School of Automation
Beijing Institute of Technology
Beijing, China

Yuan Huang
School of Automation
Beijing Institute of Technology
Beijing, China

Junzheng Wang
School of Automation
Beijing Institute of Technology
Beijing, China

Ling Shi
Department of Electronic and Computer Engineering
Hong Kong University of Science and Technology
Hong Kong, China

ISSN 2198-4182 ISSN 2198-4190 (electronic)
Studies in Systems, Decision and Control
ISBN 978-981-16-0292-4 ISBN 978-981-16-0293-1 (eBook)
https://doi.org/10.1007/978-981-16-0293-1

Jointly published with Science Press
The print edition is not for sale in China (Mainland). Customers from China (Mainland) please order the print book from: Science Press.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

To our families.

Preface

Control systems are composed of processes, sensors, actuators, and controllers. In the era of digital systems, we usually implement control algorithms through digital processors. This inevitably makes control systems to have a sampled-data nature, namely, the controlled processes operate in continuous time, while digital controllers provide control commands only at discrete sampling instants. The study of sampled-data control systems aims at dealing with the discrepancy between continuous evolution of physical system dynamics and the discrete update of computer control algorithms, and the primary idea is to analyze the effect of sampling. Earlier investigations focus on controller analysis and design based on periodic sampling, in which the process is sampled and controlled based on constant and equidistant sampling periods. Recently, to make efficient use of the limited communication and computation resources in networked control systems, event-based sampled-data control also received significant research attention. In an event-based control system, sampling and control are not performed until certain prespecified conditions are violated and sampling periods become event-triggered and nonuniform, which adds to the difficulty in analysis and design.

We started to work on active disturbance rejection control (ADRC) when we were trying to find a simple but theoretically sound approach to event-triggered control. At that time, event-triggered control had been investigated in the control community for a couple of years, with several interesting control frameworks considered (e.g., H_∞ control, model predictive control, to name a few), and different conditions were proposed to ensure the stability and performance of the event-triggered closed-loop control system. Our motivation, however, is that the theoretical efficiency and performance of event-triggered sampled-data control was not yet demonstrated for simple and easy to implement controllers—not even the PID controllers, and the effect of event-triggering mechanism on closed-loop control performance was not quantitatively characterized. In this regard, ADRC, a nontrivial generalization of the classic PID control method originally proposed and developed by Prof. Jingqing Han at the Chinese Academy of Sciences, seems to be an ideal candidate for our study due to its simple structure and its popularity and success in different industrial applications. On the other hand, the existing theoretic analysis of ADRC mainly focused on the continuous-time formulation of the controller and the effect of sampled-data implementation did not receive significant attention. In a certain sense, the study of event-triggered ADRC also provides a new possibility of analyzing the sampled-data performance of this controller.

Over the years, the theoretic developments and applications on event-triggered ADRC have been published in well-recognized journals; however, a comprehensive summary of the results is also necessary because the core ideas behind the design need to be synthesized to help the readers understand the development and motivate further study of the open problems, which is the purpose of this monograph.

As a prerequisite, an ideal reader would have knowledge of modern control theory and sampled-data systems, although we have included detailed proofs of the results in this book to make it self-contained.

The book starts with an introductory chapter, which introduces the basics of sampled-data systems, event-based sampled-data control, ADRC, and the related literature. The rest of the book is then divided into two parts. The first part covers theoretic developments, including the first attempt on discrete-time extended state observer (ESO), the developments of event-triggered ESO and ADRC, and the extensions to high-gain observer-based control. The second part presents a few application examples, including numerical application to attitude control of spacecraft system, and experimental results on DC motors and electrical cylinders. The last example is an artificial pancreas system that is used to achieve closed-loop glucose control for the patient with type 1 diabetes, the aim of which is not to purely illustrate event-based ADRC, but to motivate the future direction of event-based learning and control parameter adaptation.

This book would not have been possible without the help and support from many people and funding agencies. In particular, Dawei Shi wishes to thank his students, Jian Xue, Deheng Cai, Jiliang Song, Jing Chen, and Kaixin Cui, with whom he collaborated on event-triggered ADRC. Dawei Shi is also grateful to Prof. Tongwen Chen at the University of Alberta, Canada, who led him to the field of sampled-data systems and event-triggered control. Finally, he would also like to thank Prof. Francis J. Doyle III and Dr. Eyal Dassau at the Harvard University, USA, for offering the postdoc opportunity to work on artificial pancreas and closed-loop drug delivery, which made the discussions in Chap. 9 of the book possible. Financial support from National Natural Sciences Foundation of China (Grant Nos. 61973030 and 61503027) and Beijing National Natural Sciences Foundation (Grant No. 4192052) is gratefully acknowledged.

Yuan Huang would like to thank Prof. Shun-Ichi Azuma from Nagoya University, Japan, for hosting him as a visiting student, during which many interesting ideas on sampled-data systems were developed and investigated.

Ling Shi wishes to thank his Ph.D. students, Junfeng Wu, Chao Yang, Duo Han, and Yuzhe Li for a series of joint work on event-based state estimation and its applications. He would also like to thank his long-term collaborators on this topic: Prof. Karl H. Johansson (KTH), Dr. Yilin Mo (NTU), Prof. Bruno Sinopoli (CMU), Prof. Huanshui Zhang (Shandong U), and Prof. Qing-shan Jia (Tsinghua U). He is grateful for the financial support from the Hong Kong Research Grant Council and from the Hong Kong University of Science and Technology.

Junzheng Wang would like to thank his student Dongchen Liu for the joint work on event-based ADRC of electric cylinders. He gratefully acknowledges financial support from National Natural Sciences Foundation of China (Grant No. 51675041).

Finally, the authors would like to thank Lisa Fan from Springer and Ding Yu from China Science Publishing & Media Ltd. for their efficient handling of this joint book project from the early stage.

Beijing, China	Dawei Shi
Beijing, China	Yuan Huang
Beijing, China	Junzheng Wang
Hong Kong, China	Ling Shi
December 2020	

The original version of the book was revised. The affiliation "Hong Kong, Hong Kong" of author "Ling Shi" has been changed to "Hong Kong, China". The correction to this book can be found at https://doi.org/10.1007/978-981-16-0293-1_11

Contents

Part II Applications

Acronyms

ADC	Analog to digital converter
ADRC	Active disturbance rejection control
AP	Artificial Pancreas
BIBS	Bounded input bounded state
DAC	Digital to analog converter
DC	Direct current
ESO	Extended state observer
ET-ADRC	Event-triggered active disturbance rejection control
ET-ESO	Event-triggered extended state observer
HGO	High-gain observer
MPC	Model predictive control
PID	Propotional-integral-derivative
T1DM	Type 1 diabetes mellitus
TD	Tracking differentiator
ZOH	Zero-order hold