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Event-Triggered Active Disturbance Rejection Control

Theory and Applications

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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.

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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

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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	Proportional-integral-derivative
T1DM	Type 1 diabetes mellitus
TD	Tracking differentiator
ZOH	Zero-order hold