



Review Article

Sampled-data control systems with non-uniform sampling: A survey of methods and trends^aXian-Ming Zhang^a, Qing-Long Han^{a,*}, Xiaohua Ge^b, Boda Ning^b, Bao-Lin Zhang^c^a School of Science, Computing, and Engineering Technology, Swinburne University of Technology, Melbourne, VIC 3122, Australia^b Centre for Smart Infrastructure and Digital Construction, Swinburne University of Technology, Melbourne, VIC 3122, Australia^c College of Automation and Electronic Engineering, Qingdao University of Science & Technology, Qingdao, Shandong 266061, China

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ABSTRACT

The convergence of sensing, computing, communication and control elements drives the traditional point-to-point control systems towards networked control systems. Sampled-data control systems, which focus on the significant interplay between sampling and control, play a critical role in modern networked control systems, including intelligent transportation systems, smart grids, and advanced manufacturing systems. This paper presents a survey of methods and trends in non-uniform sampled-data control systems, where sampling and control actions are performed in an aperiodic manner. First, some fundamental issues of both continuous- and discrete-time sampled-data control systems are discussed. Next, main methods in both continuous-time and discrete-time domains are elaborated, respectively. Then, event-triggered sampling, under which sampling is executed only when the system needs attention, is examined. Typical triggering mechanisms in the existing literature are reviewed and classified into four types according to different threshold functions. Furthermore, two applications in terms of automated vehicle platoons and islanded microgrids are provided to demonstrate that sampled-data control methods are capable to support relevant practical application scenarios. Finally, several challenging issues are envisioned to direct future research.

1. Introduction

Sampled-data systems have been studied for over seven decades (Clarke, 1951). When sampling is periodic, there has been the mature theory for stability analysis and control design of sampled-data systems; see, e.g., Apkarian and Adams (1998), Chen and Francis (1995), Nevic and Teel (2001), Oishi (2001) and Yamamoto (2019). Undoubtedly, the mature theory has laid a solid foundation for networked control systems (NCSs). However, in practical scenarios, the sampling intervals between two consecutive sampling instants in an NCS are usually time-varying rather than constant (Gupta & Chow, 2010; Hespanha, 2014; Hu, Ren, Deng, & Li, 2022; Lu, Wen, Lu, Wang, & Zhang, 2022; Mahmood & Hamdan, 2018). For example, when an NCS is subject to packet dropouts or denial-of-service (DoS) attacks, it can be modelled as a sampled-data system with non-uniform sampling (Hoemela, Teel, van de Wouw, & Neuk, 2010; Hespanha, Naghshtabrizi, & Xu, 2007; Liu, Shtyrov, & Fridman, 2019; Pang, Bai, Liu, Han, & Zhang, 2021; Zhang, Han, Ge, & Ding, 2020; Zhang, Han, Ge, et al., 2020), sometimes also known as aperiodic sampling and variable sampling.

The frequency of sampling actions for a sensor or sampler device should be proactively reduced due to the constrained resource budget. For example, real-world sensor and sampler devices are often battery-operated. Persistent or periodic sampling of the continuous-time signal of interest that has little fluctuation since the last sampling time inevitably causes unnecessary power consumption. In this case, event-triggered sampling is regarded as a promising sampling mechanism to reduce the potential resource consumption (Borgers & Hoemela, 2014; Hoemela, Sanden, & Van Den Bosch, 2008; Tabuada, 2007; Tiberi, Fischione, Johansson, & Benedetto, 2013). On the other hand, the core of NCSs is the communication network that enables data transmissions between networked sensors and controllers. However, communication resources such as bandwidth are often limited (Hespanha et al., 2007; Zhang, Han, & Ge, 2022). In this sense, the event-triggered sampling is prevalently employed to reduce the transmission frequency only when ‘needed’, e.g., when the current signal of interest suffers from a significant change from the last sampling and transmitting instant. The promising benefit of saving precious resources represents the primary

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Theory Of Sample Data Control Systems

Julius T. Tou



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Ibrahim Jury, 1977 **Sampled-Data Control Systems** Jürgen Ackermann, 2012-12-06 The first German edition of this book appeared in 1972 and in Polish translation in 1976 It covered the analysis and synthesis of sampled data systems The second German edition of 1983 extended the scope to design in particular design for robustness of control system properties with respect to uncertainty of plant parameters This book is a revised translation of the second German edition The revisions concern primarily a new treatment of the finite effect sequences and the use of nice numerical properties of Hessenberg forms The introduction describes examples of sampled data systems in particular digital controllers and analyzes the sampler and hold also some design aspects are introduced Chapter 2 reviews the modelling and analysis of continuous systems Pole shifting is formulated as an affine mapping here some new material on fixing some eigenvalues or some gains in a design step is included Chapter 3 treats the analysis of sampled data systems by state space and z transform methods This includes sections on inter sampling behavior time delay systems absolute stability and non synchronous sampling Chapter 4 treats controllability and reach ability of discrete time systems controllability regions for constrained inputs and the choice of the sampling interval primarily under controllability aspects Chapter 5 deals with observability and constructability both from the discrete and continuous plant output Full and reduced order observers are treated as well as disturbance observers

Theory of Sampled Data Control Systems David P. Lindorff, 1965 Analysis and Synthesis of Sampled-data Control Systems Benjamin C. Kuo, 1963 **Introduction to Control Systems** D K Anand, 2013-10-22 This book is written for use as a text in an introductory course in control systems The classical as well as the state space approach is included and integrated as much as possible The first part of the book deals with analysis in the time domain All the graphical techniques are presented in one chapter and the latter part of the book deals with some advanced material It is intended that the student should already be familiar with Laplace transformations and have had an introductory course in circuit analysis or vibration theory To provide the student with an understanding of correlation concepts in control theory a new chapter dealing with stochastic inputs has been added Also Appendix A has been significantly expanded to cover the theory of

Laplace transforms and z transforms The book includes worked examples and problems for solution and an extensive bibliography as a guide for further reading

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