

LINEAR TIME LOGIC CONTROL OF DISCRETE-TIME LINEAR SYSTEMS

PAULO TABUADA AND GEORGE J. PAPPAS

ABSTRACT. The control of complex systems poses new challenges that fall beyond the traditional methods of control theory. One of these challenges is given by the need to control, coordinate and synchronize the operation of several interacting submodules within a system. The desired objectives are no longer captured by usual control specifications such as stabilization or output regulation. Instead, we consider specifications given by Linear Temporal Logic (LTL) formulas. We show that existence of controllers for discrete-time controllable linear systems and LTL specifications can be decided and that such controllers can be effectively computed. The closed-loop system is of hybrid nature, combining the original continuous dynamics with the automatically synthesized switching logic required to enforce the specification.

1. INTRODUCTION

1.1. Motivation. In recent years there has been an increasing interest in extending the application domain of systems and control theory from monolithic continuous plants to complex systems consisting of several concurrently interacting submodules. Examples range from multi-modal software control systems in the aerospace [DS97, LL00, TH04] and automotive industry [CJG02, SH05] to advanced robotic systems [KBr04, MSP05, DCG⁺05]. This change in perspective is accompanied by a shift in control objectives. One is no longer interested in the stabilization or output regulation of individual continuous plants, but rather wishes to regulate the global system behavior¹ through the local control of each individual submodule or component. Typical specifications for this class of control problems include coordination and synchronization of individual modules, sequencing of tasks, reconfigurability and adaptability of components, etc. In order to address this emerging class of control problems we need to formally specify the desired system behavior:

How can we formally and succinctly specify the desired behavior of concurrently interacting systems?

The specification mechanism should also lead to controller design methods. These controllers will enforce a hybrid behavior on the controlled system since system evolution is influenced both by the continuous dynamics and by the discrete interaction (communication) between submodules. While many ad-hoc approaches have been reported in the literature for the design of such hybrid systems, any formal guarantee of operation can only be obtained through formal verification which is noticeably a hard² problem [HKP⁺98]. This suggests that one should aim at design methods that satisfy the specification by construction:

How can we design (hybrid) controllers ensuring satisfaction of specifications by construction, thereby avoiding or substantially reducing the need for formal verification?

Another dimension of this problem, that should not be neglected, is its computational aspect. As the number of modules increases, the possibilities of interaction between modules also increase thus rendering analysis of global behavior an extremely difficult task. This intrinsic complexity of concurrently interacting systems can only be addressed by computational synthesis methods, reducing error-prone human analysis or synthesis to the strictly necessary minimum. Only fully automated methods have the potential to scale and successfully address control problems for systems consisting of large numbers of interacting components:

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¹We use the term behavior in a rather informal way to refer to the set of system's trajectories that can be observed.

²Verification of simple specifications such as reachability is unfortunately undecidable for a large majority of systems of interest.

Discrete Linear Control Systems

Chi-Tsong Chen



Discrete Linear Control Systems:

Analysis and Design of Discrete Linear Control Systems Vladimír Kučera,1991 **Discrete Linear Control Systems** V.N. Fomin,2011-09-01 **Introduction to Discrete Linear Controls** Albert B. Bishop,2014-05-10 Introduction to Discrete Linear Controls Theory and Applications focuses on the design analysis and operation of discrete time decision processes The publication first offers information on systems theory and discrete linear control systems discrete control system models and the calculus of finite differences Discussions focus on the calculus of finite differences and linear difference equations summations control of cylinder diameter generalized discrete process controller with sampling difference equations control theory and system models The text then examines classical solution of linear difference equations with constant inverse transformation and measures and environmental effects of system performance The manuscript takes a look at parameter selection in first order systems considering sampling and instrumentation errors second order systems and system instability including responses of the generalized second order process controller criterion for stability of discrete linear systems and proportional plus difference control The publication is a valuable source of information for engineers operations researchers and systems analysts *Discrete-time Control Systems* Katsuhiko Ogata,1995 In depth discussions of selected topics such as Z transform and pole placement when the control signal was a vector quantity have been moved to optional Appendices discusses in detail the theoretical background for designing control systems offers a greatly expanded treatment of the pole placement design with minimum order observer by means of state space approach Ch 6 and polynomial equations approach Ch 7 features a new chapter on the polynomial equations approach to the control systems design as an alternative to the design of control systems via pole placement with minimum order observers Includes the design of model matching control systems emphasizes the usefulness of MATLAB for studying discrete time control systems showing how to use MATLAB optimally to obtain numerical solutions that involve various types of vector matrix operations plotting response curves and system design based on quadratic optimal control presents many instructive examples and worked out problems throughout the entire book **Discrete-time and Computer Control Systems** James A. Cadzow,Hinrich R. Martens,1970 Treats systems in which the digital computer plays a central role *Numerical Methods for Linear Control Systems* Biswa Datta,2004-02-24 Numerical Methods for Linear Control Systems Design and Analysis is an interdisciplinary textbook aimed at systematic descriptions and implementations of numerically viable algorithms based on well established efficient and stable modern numerical linear techniques for mathematical problems arising in the design and analysis of linear control systems both for the first and second order models Unique coverage of modern mathematical concepts such as parallel computations second order systems and large scale solutions Background material in linear algebra numerical linear algebra and control theory included in text Step by step explanations of the algorithms and examples *Introduction To Control Systems, An (2nd Edition)* Kevin Warwick,1996-01-31 This significantly revised edition presents a

broad introduction to Control Systems and balances new modern methods with the more classical. It is an excellent text for use as a first course in Control Systems by undergraduate students in all branches of engineering and applied mathematics. The book contains a comprehensive coverage of automatic control integrating digital and computer control techniques and their implementations, the practical issues and problems in Control System design, the three term PID controller, the most widely used controller in industry today, numerous in chapter worked examples and end of chapter exercises. This second edition also includes an introductory guide to some more recent developments, namely fuzzy logic control and neural networks.

Positive Discrete Linear Control Systems with Bounded Inputs and Graded Manpower Systems Ampon Dhamacharoen, 1986

Modern Control Engineering P.N. Paraskevopoulos, 2001-11-15. Illustrates the analysis, behavior and design of linear control systems using classical, modern and advanced control techniques. Covers recent methods in system identification and optimal, digital, adaptive, robust and fuzzy control, as well as stability, controllability, observability, pole placement, state observers, input/output decoupling and model matching.

Positive 1D and 2D Systems Tadeusz Kaczorek, 2012-12-06. In the last decade a dynamic development in positive systems has been observed. Roughly speaking, positive systems are systems whose inputs, state variables and outputs take only nonnegative values. Examples of positive systems are industrial processes involving chemical reactors, heat exchangers and distillation columns, storage systems, compartmental systems, water and atmospheric pollution models. A variety of models having positive linear system behaviour can be found in engineering, management science, economics, social sciences, biology and medicine etc. The basic mathematical tools for analysis and synthesis of linear systems are linear spaces and the theory of linear operators. Positive linear systems are defined on cones and not on linear spaces. This is why the theory of positive systems is more complicated and less advanced. The theory of positive systems has some elements in common with theories of linear and non linear systems. Schematically the relationship between the theories of linear, non linear and positive systems is shown in the following figure.

Figure 1

Discrete-Time Control System Design with Applications C.A. Rabbath, N. Léchevin, 2013-12-02. This unique book provides a bridge between digital control theory and vehicle guidance and control practice. It presents practical techniques of digital redesign and direct discrete time design suitable for a real time implementation of controllers and guidance laws at multiple rates and with and without computational techniques. The theory of digital control is given as theorems, lemmas and propositions. The design of the digital guidance and control systems is illustrated by means of step by step procedures, algorithms and case studies. The systems proposed are applied to realistic models of unmanned systems and missiles and digital implementation.

Computer-Controlled Systems with Delay Efim N. Rosenwasser, Bernhard P. Lampe, Torsten Jentsch, 2019-05-22. Computer Controlled Systems with Delay is a systematic study of the problems of analysis and synthesis for multidimensional sampled data SD systems with delay. It is based on the frequency polynomial method in which the concept of a parametric transfer matrix PTM plays a key role. Until now no alternative general methods have been

available to solve the above problems The text is divided into three parts background information from the theory of polynomial and rational matrices helps the reader to acquire the basic understanding necessary to use the main content of the book without addressing additional sources methods for the mathematical description of multidimensional SD systems with delay based on the concept of the PTM and optimization methods for multidimensional SD systems with delay including H2 and L2 optimization as well as H2 optimization for colored input signals The monograph is completed by three appendices An algorithm for constructing the set of pathological sampling periods for a continuous SISO object with delay is provided first MATLAB toolbox algorithms representing methods described in the book and application examples for selected optimization problems are given in the second A solution to the problem of guaranteeing the required performance in a class of stochastic disturbances for SD systems with delay is considered in the third Computer Controlled Systems with Delay is intended for engineers scientists and teachers working in modern control theory It will also benefit post graduate students taking courses in related disciplines The book continues the description of the authors research results on developing methods for SD systems theory which are based on the PTM concept and published in the monographs Computer Controlled Systems and Multivariable Computer controlled Systems **The ARIMA and VARIMA Time Series** Ky M. Vu, 2007-08

Discrete-data Control Systems Benjamin C. Kuo, 1974 *Scientific and Technical Aerospace Reports*, 1964 Control Theory and Advanced Technology, 1994 **Discrete Linear Control** Vladimír Kučera, 1979 Good No Highlights No Markup all pages are intact Slight Shelfwear may have the corners slightly dented may have slight color changes slightly damaged spine **Linear Optimal Control Systems** Huibert Kwakernaak, Ráphel Sivan, 1972-11-10 This book attempts to reconcile modern linear control theory with classical control theory One of the major concerns of this text is to present design methods employing modern techniques for obtaining control systems that stand up to the requirements that have been so well developed in the classical expositions of control theory Therefore among other things an entire chapter is devoted to a description of the analysis of control systems mostly following the classical lines of thought In the later chapters of the book in which modern synthesis methods are developed the chapter on analysis is recurrently referred to Furthermore special attention is paid to subjects that are standard in classical control theory but are frequently overlooked in modern treatments such as nonzero set point control systems tracking systems and control systems that have to cope with constant disturbances Also heavy emphasis is placed upon the stochastic nature of control problems because the stochastic aspects are so essential Preface **Analog and Digital Control System Design** Chi-Tsong Chen, 1993 This text's contemporary approach focuses on the concepts of linear control systems rather than computational mechanics Straightforward coverage includes an integrated treatment of both classical and modern control system methods The text emphasizes design with discussions of problem formulation design criteria physical constraints several design methods and implementation of compensators Discussions of topics not found in other texts such as pole placement model matching and robust tracking add to the text's

cutting edge presentation Students will appreciate the applications and discussions of practical aspects including the leading problem in developing block diagrams noise disturbances and plant perturbations State feedback and state estimators are designed using state variable equations and transfer functions offering a comparison of the two approaches The incorporation of MATLAB throughout the text helps students to avoid time consuming computation and concentrate on control system design and analysis *State Space Theory of Discrete Linear Control* Vladimír Strejc,1981

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