

Chapter 2

CONTROL OF BILINEAR SYSTEMS

Bilinear systems are an important subclass of nonlinear systems with numerous applications in engineering, biology, and economics (Mohler, 1973; Espana and Landau, 1978; Brockett, 1979; Baillieul, 1978, 1998). Most papers consider time-invariant continuous bilinear systems with linear feedback. In almost all references stability problems are studied using a sufficient condition for the existence of a feedback control. These studies usually do not deal with stability problems with a large class of inputs as considered here. The linear-quadratic optimal control problem is apparently one of the simplest and most thoroughly studied. It is not surprising, therefore, that the nonlinear analogues of this problem have long since attracted the attention of control scientists (Andreev, 1982; Aganovic, 1995; Bloch and Crouch, 1996; Bloch, 1998; Jurdjevic, 1998; Agrachev and Sachkov, 2004). The symplectic structure of the linear-quadratic problem was also studied in Faibusovich (1988a, 1991), and has naturally led to the question of nonlinear generalizations.

In this chapter we consider optimal control problems for nonlinear systems. In Section 1 we demonstrate how to reduce this problem to the equivalent problem for bilinear systems. Then we investigate an optimal control problem for nonlinear systems through necessary conditions of optimality. We apply soliton methods and Pontryagin's principle to the optimal control problem. We give theoretical justification for the equations in the Lax form, which can be constructed from the Hamiltonian system arising through the expression of the necessary optimality conditions. The Lax forms we consider, extend and unify similar results obtained previously in the publications on optimal control of bilinear systems. The theoretical justification was done by V. Yatsenko (1984).

Bilinear Control Systems

Yonggang Chou

Bilinear Control Systems

Bilinear Control Systems David Elliott,2009-09-01 The mathematical theory of control became a field of study half a century ago in attempts to clarify and organize some challenging practical problems and the methods used to solve them It is known for the breadth of the mathematics it uses and its cross disciplinary vigor Its literature which can be found in Section 93 of Mathematical Reviews was at one time dominated by the theory of linear control systems which mathematically are described by linear differential equations forced by additive control inputs That theory led to well regarded numerical and symbolic computational packages for control analysis and design Nonlinear control problems are also important in these either the underlying dynamical system is nonlinear or the controls are applied in a nonadditive way The last four decades have seen the development of theoretical work on nonlinear control problems based on differential manifold theory nonlinear analysis and several other mathematical disciplines Many of the problems that had been solved in linear control theory plus others that are new and distinctly nonlinear have been addressed some resulting general definitions and theorems are adapted in this book to the bilinear case **Bilinear Control Systems** David Elliott,2009-05-18 The mathematical theory of control became a field of study half a century ago in attempts to clarify and organize some challenging practical problems and the methods used to solve them It is known for the breadth of the mathematics it uses and its cross disciplinary vigor Its literature which can be found in Section 93 of Mathematical Reviews was at one time dominated by the theory of linear control systems which mathematically are described by linear differential equations forced by additive control inputs That theory led to well regarded numerical and symbolic computational packages for control analysis and design Nonlinear control problems are also important in these either the underlying dynamical system is nonlinear or the controls are applied in a nonadditive way The last four decades have seen the development of theoretical work on nonlinear control problems based on differential manifold theory nonlinear analysis and several other mathematical disciplines Many of the problems that had been solved in linear control theory plus others that are new and distinctly nonlinear have been addressed some resulting general definitions and theorems are adapted in this book to the bilinear case **Bilinear Control Systems** Stanley Moseley,2017-06-21 Bilinear Control Systems the theory of linear control systems which mathematically are described by linear differential equations forced by additive control inputs That theory led to well regarded numerical and symbolic computational packages for control analysis and design Nonlinear control problems are also important in these either the underlying dynamical system is nonlinear or the controls are applied in a nonadditive way The last four decades have seen the development of theoretical work on nonlinear control problems based on differential manifold theory nonlinear analysis and several other mathematical disciplines Many of the problems that had been solved in linear control theory plus others that are new and distinctly nonlinear have been addressed some resulting general definitions and theorems are adapted in this book to the bilinear case **An Exhaustive Delineation of Bilinear Control Systems**

Hamidreza Momeni,1979 Linear Optimal Control of Bilinear Systems Zijad Aganovic,Zoran Gajic,2014-03-12 This book is designed to be a comprehensive treatment of linear methods to optimal control of bilinear systems The unified theme of this book is the use of dynamic programming in order to simplify and decompose required computations for the optimal control of bilinear quadratic systems There are numerous examples of bilinear control systems that provide great challenges to engineers mathematicians and computer scientists these include nuclear reactors missile intercept problems and mechanical brake systems The book also examines two special classes of bilinear quadratic control problems namely singularly perturbed and weakly coupled bilinear control systems The usefulness of the presented methods to these two types of control problem is demonstrated by several real control system examples

Bilinear Control Systems David Elliott,2009-05-18

The mathematical theory of control became a field of study half a century ago in attempts to clarify and organize some challenging practical problems and the methods used to solve them It is known for the breadth of the mathematics it uses and its cross disciplinary vigor Its literature which can be found in Section 93 of Mathematical Reviews was at one time dominated by the theory of linear control systems which mathematically are described by linear differential equations forced by additive control inputs That theory led to well regarded numerical and symbolic computational packages for control analysis and design Nonlinear control problems are also important in these either the underlying dynamical system is nonlinear or the controls are applied in an additive way The last four decades have seen the development of theoretical work on nonlinear control problems based on differential manifold theory nonlinear analysis and several other mathematical disciplines Many of the problems that had been solved in linear control theory plus others that are new and distinctly nonlinear have been addressed some resulting general definitions and theorems are adapted in this book to the bilinear case

The Equivalence of Nonlinear and Bilinear Control Systems Jackson Lee Sedwick,Washington University (Saint Louis, Mo.),1974

Optimization and Control of Bilinear Systems Panos M. Pardalos,Vitaliy A. Yatsenko,2010-03-14 The present book is based on results of scientific investigations and on the materials of special courses offered for graduate and undergraduate students The purpose of this book is to acquaint the reader with the developments in bilinear systems theory and its applications Particular attention is paid to control of open physical processes functioning in a nonequilibrium mode The text consists of eight chapters Chapter 1 is concerned with the problems of systems analysis of bilinear processes Chapter 2 solves the problem of optimal control of bilinear systems on the basis of differential geometry methods Chapter 3 deals with the progress made in an adaptive estimation technique Chapter 4 is devoted to the application of the Yang Mills fields to investigation of nonlinear control problems Chapter 5 considers intelligent sensors used to examine weak signals This chapter also describes and analyzes bilinear models of intelligent sensing elements Chapter 6 illustrates control problems of a quantum system Chapter 7 discusses the problems of control and identification in systems with chaotic dynamics Finally Chapter 8 examines the controlled processes running in biomolecular systems This book is directed to students postgraduate students and specialists engaged in

the fields of control of physical processes quantum and molecular computing biophysics and physical information science

Bilinear Control Processes with Application to Immunology Chin-Shung Hsu, 1978 As a significant class of nonlinear systems bilinear systems BLS are extensively developed in the past years In addition to their advantages over linear systems which are often not adequate to represent accurately many control processes the BLS are particularly appealing in modeling biological systems in which parametric controls are of fundamental importance This dissertation is aimed at making a contribution to the theory of bilinear control systems via Lie algebraic methods and the application of accomplished results in immunology To this end the input output relationship of BLS is studied in terms of Volterra series expansion which provides a convenient tool in examining the BLS stability as well as controllability Moreover the Volterra series associated with a BLS is in general an infinite series and thus in practice it is important to know how many terms are required to prevent the truncation error from exceeding the maximum allowance Criteria of acquiring prescribed accuracy in terms of finite Volterra series are derived for BLS with uniformly bounded input or with exponentially stable linear subsystems The problem of inverse system design which is capable of identifying both the input function and the state variables based upon the output data is also considered The observer theory of constant linear systems is then extended into a special class of bilinear systems with input matrices of rank one In view of the functional similarity between immune processes and parametric control systems a mathematical model of humoral immune response is presented and analyzed The structural aspects of this nonlinear immune model is examined with the aid of bilinear control theory Approximate immune models which are amenable to the control theoretic analysis via foregoingly developed techniques are proposed Some computer simulations are performed to show that the form of model responses is reasonable by comparing with the experimental data

Some Results on Bilinear Control Systems with Rank-one Inputs Yonggang Chou, 1995 **Bilinear Control Processes: with Applications to Engineering, Ecology, and Medicine** Mohler, 1974-03-11 Bilinear Control Processes with

Applications to Engineering Ecology and Medicine Numerical Stabilization of Bilinear Control Systems Lars Grüne, 1996

Structural Controllability of Driftless Bilinear Control Systems Aristomenis Tsopelakos, 2016 Bilinear Control Systems Walter Evans, 2017-02-22 Providing readers with a detailed examination of resilient controls in risk averse decision this monograph is aimed toward researchers and graduate students in applied mathematics and electrical engineering with a systems theoretic concentration This work contains a timely and responsive evaluation of reforms on the use of asymmetry or skewness pertaining to the restrictive family of quadratic costs that have been appeared in various scholarly forums Additionally the book includes a discussion of the current and ongoing efforts in the usage of risk dynamic game decision optimization and disturbance mitigation techniques with output feedback measurements tailored toward the worst case scenarios This work encompasses some of the current changes across uncertainty quantification stochastic control communities and the creative efforts that are being made to increase the understanding of resilient controls Specific

considerations are made in this book for the application of decision theory to resilient controls of the linear quadratic class of stochastic dynamical systems *Nonlinear Control Systems Design 1989* A. Isidori, 2014-05-23 In the last two decades the development of specific methodologies for the control of systems described by nonlinear mathematical models has attracted an ever increasing interest New breakthroughs have occurred which have aided the design of nonlinear control systems However there are still limitations which must be understood some of which were addressed at the IFAC Symposium in Capri The emphasis was on the methodological developments although a number of the papers were concerned with the presentation of applications of nonlinear design philosophies to actual control problems in chemical electrical and mechanical engineering **Type II Balanced Truncation for Deterministic Bilinear Control Systems** Martin Redmann, 2017 When solving partial differential equations numerically usually a high order spatial discretisation is needed Model order reduction MOR techniques are often used to reduce the order of spatially discretised systems and hence reduce computational complexity A particular MOR technique to obtain a reduced order model ROM is balanced truncation BT a method which has been extensively studied for deterministic linear systems As so called type I BT it has already been extended to bilinear equations an important subclass of nonlinear systems We provide an alternative generalisation of the linear setting to bilinear systems which is called type II BT The Gramians that we propose in this context contain information about the control It turns out that the new approach delivers energy bounds which are not just valid in a small neighbourhood of zero Furthermore we provide an H1 error bound which so far is not known when applying type I BT to bilinear systems

Linear Optimal Control of Bilinear Systems Aganović Zijad, 1995 **Nonlinear Systems: Applications to bilinear control** Ronald R. Mohler, 1991 *Numerical Stabilization of Bilinear Control Systems* L. Grüne, 1994 *System Structure and Control 1992* V. Strejc, 2014-06-28 Provides a useful reference source on system structure and control Covers linear systems nonlinear systems robust control implicit system chaotic systems singular and time varying systems

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