

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; Jurdjević, 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 Bilinear Control Systems

**Alexandre Seuret, Laurentiu
Hetel, Jamal Daafouz, Karl H. Johansson**



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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 non 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

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 non 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 *Some Results on Bilinear Control Systems with Rank-one Inputs* Yonggang Chou, 1995

Nonlinear Systems: Applications to bilinear control Ronald R. Mohler, 1991 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 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

Delays and Networked Control Systems Alexandre Seuret, Laurentiu Hetel, Jamal Daafouz, Karl H. Johansson, 2016-06-07 This edited monograph includes state of the art contributions on continuous time dynamical networks with delays The book is divided into four parts The first part presents tools and methods for the analysis of time delay systems with a particular attention on control problems of large

scale or infinite dimensional systems with delays The second part of the book is dedicated to the use of time delay models for the analysis and design of Networked Control Systems The third part of the book focuses on the analysis and design of systems with asynchronous sampling intervals which occur in Networked Control Systems The last part of the book exposes several contributions dealing with the design of cooperative control and observation laws for networked control systems The target audience primarily comprises researchers and experts in the field of control theory but the book may also be beneficial for graduate students

An Exhaustive Delineation of Bilinear Control Systems Hamidreza Momeni, 1979

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