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Frequency Domain State-Space System Identification

This paper presents an algorithm for identifying state-space models of linear systems from frequency response data. A matrix-fraction description of the transfer function is employed to convert the frequency response data, using the least-squares method. The parameters of the matrix-fraction representation are then used to construct the Markov parameters of the system. Finally, state-space models are obtained through the Eigensystem Realization Algorithm using the Markov parameters. The main advantage of this approach is that the curve-fitting and the Markov-parameter-contraction are linear problems which avoid the difficulties of non-linear optimization of other approaches. Another advantage is that it avoids windowing distortions associated with other frequency domain methods.

Introduction

State-space models of dynamic systems are usually required for many current control design methods as these control approaches are developed based upon some state-space representation of the system. Recently, it has been found that state-space models can be effectively identified through the Observer/Kalman Filter System Identification method (OKSIF) using time domain input-output data (Phares et al., 1991, 1992; Juang et al., 1991; Chen et al., 1992). However, there are cases in which frequency response data rather than time histories are available. This is often the case with the advent of sophisticated spectrum analyzers and associated automatic test equipment. Therefore, the technique of obtaining state-space models from frequency response data is of practical interest.

Classically, the Inverse Discrete Fourier Transform method (IDFT) is used to transform frequency response data to time domain data, that is, to transform the frequency response function (FRF) of the system to its pulse response. The pulse response of discrete-time systems is also known as the Markov parameters. The disadvantage of this approach is that the Markov parameter sequence thus obtained is distorted by truncating effects (Oppenheim and Schaffer, 1975).

Recently, a method called the State-Space Frequency Domain (SSFD) identification algorithm (Boyard, 1992) has been developed. This method can estimate Markov parameters from the FRF without windowing distortion and an arbitrary frequency weighting can be introduced to shape the estimation error. The method uses a rational matrix description (the ratio of a matrix polynomial and a scalar scalar polynomial denominator) to curve-fit the frequency data, and obtains the Markov parameters from this equation. In obtaining the state-space models from the Markov parameters, the Eigensystem

Realization Algorithm (ERA) (Jiang and Pappas, 1985) or its variant ERA/DC (Juang et al., 1990) is used. The disadvantage of this method is that the curve-fitting problem must be solved either by nonlinear optimization techniques or by linear approximation algorithms requiring several iterations (Boyard, 1992).

This paper proposes a simple yet effective way of curve-fitting the FRF data and of constructing the Markov parameters. Instead of using a rational matrix function, this method uses a matrix-fraction for the curve-fitting. Thus the curve-fitting is reformulated as a linear problem which can be solved by the ordinary least-squares method in one step; that is, no iteration is required. The method can match the frequency response data perfectly if the FRF is accurate in an ideal case, and will seek an optimal match if noise and/or distortion are involved in the data. This new approach retains all the advantages associated with the SSFD while avoiding the iterative, approximate curve-fitting procedures.

Section 2 gives some background and the notation used for this problem. Section 3 discusses the curve-fitting method while Section 4 describes a method to compute the Markov parameters from the parameters obtained from curve-fitting. The process of going from the Markov parameters to a state-space model is discussed in Section 5. Finally, simulated data from a model of the Mini-Mac structure and experimental data from a NASA method are used in Section 6 as illustrative examples. The simulated data discuss an ideal FRF case (without distortion and noise) whereas the experimental data present a practical case. The illustrative examples show that the method is effective in both cases.

Background and Notation

The objective of frequency domain state-space system identification is to identify state-space models from the given fre-

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Frequency Domain And State Space Methods For Linear Systems

Philipp K. Janert



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Frequency Domain and State Space Methods for Linear Systems Christopher I. Byrnes, Anders Lindquist, 1986 Very Good No Highlights or Markup all pages are intact Control System Design Bernard Friedland, 2005-03-24 Introduction to state space methods covers feedback control state space representation of dynamic systems and dynamics of linear systems frequency domain analysis controllability and observability shaping the dynamic response and more 1986 edition **The Control Handbook (three volume set)** William S. Levine, 2018-10-08 At publication The Control Handbook immediately became the definitive resource that engineers working with modern control systems required Among its many accolades that first edition was cited by the AAP as the Best Engineering Handbook of 1996 Now 15 years later William Levine has once again compiled the most comprehensive and authoritative resource on control engineering He has fully reorganized the text to reflect the technical advances achieved since the last edition and has expanded its contents to include the multidisciplinary perspective that is making control engineering a critical component in so many fields Now expanded from one to three volumes The Control Handbook Second Edition brilliantly organizes cutting edge contributions from more than 200 leading experts representing every corner of the globe They cover everything from basic closed loop systems to multi agent adaptive systems and from the control of electric motors to the control of complex networks Progressively organized the three volume set includes Control System Fundamentals Control System Applications Control System Advanced Methods Any practicing engineer student or researcher working in fields as diverse as electronics aeronautics or biomedicine will find this handbook to be a time saving resource filled with invaluable formulas models methods and innovative thinking In fact any physicist biologist mathematician or researcher in any number of fields developing or improving products and systems will find the answers and ideas they need As with the first edition the new edition not only stands as a record of accomplishment in control engineering but provides researchers with the means to make further advances **Practical Control Engineering for Mechatronics and Automation** Fernando Martell, Irma Y. Sanchez, 2024-06-14 Production processes and engineered systems use continuous and discrete variables as well as the combination of continuous and sequential operations This volume covers both aspects thus providing knowledge in continuous and discrete control logic control and hybrid control systems It is a compilation of selected control strategies to automate processes and systems with a practical approach to ease their design analysis and implementation The selection of the control schemes is based on the capability to provide desired dynamical response or real time performance Practicality is required for achieving faster development times of automation projects or system prototypes by comprehensive presentation and direct application of methodologies and techniques for efficient and structured programming of control algorithms Considered methodologies include model based design hardware in the loop simulations and structured programming Fundamental signals and systems concepts are explained Systems and controllers are analyzed using discrete time equations which ease their implementation

in most programmable platforms without requiring sophisticated software PID based control internal model control and model reference control are viewed as powerful schemes in terms of performance and suitability for mechatronics systems because of the use of the model in their architecture as a key control element Finite state machines are presented to solve sequential requirements of direct and supervisory control of many processes and machines Cyberphysical systems are an industrial technology and an education trend distinguished by visual and dynamic models or digital twins of the physical systems The discussed analysis design and implementation practices are integrated and applied in the context of cyberphysical systems This book aims to provide multidisciplinary support to engineers and practitioners in the design of control systems and is a valuable tool for automation teaching and self learning **The Control Systems Handbook**

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design and analysis of control systems focusing on feedback stability and automation for engineering applications in various industries Advances in Statistical Control, Algebraic Systems Theory, and Dynamic Systems Characteristics Chang-Hee Won, Cheryl B. Schrader, Anthony N. Michel, 2010-07-08 Life has many surprises One of the best surprises is meeting a caring mentor an encouraging collaborator or an enthusiastic friend This volume is a tribute to Professor Michael K Sain who is such a teacher colleague and friend On the beautiful fall day of October 27 2007 friends families colleagues and former students gathered at a workshop held in Notre Dame Indiana This workshop brought together many people whose lives have been touched by Mike to celebrate his milestone 70th birthday and to congratulate him on his contributions in the fields of systems controls and control Mike was born on March 22 1937 in St Louis Missouri After obtaining his B S E E and M S E E at St Louis University he went on to study at the University of Illinois at Urbana Champaign for his doctoral degree With his Ph D degree

complete he came to the University of Notre Dame in 1965 as an assistant professor. He became an associate professor in 1968, a full professor in 1972, and the Frank M. Freimann Chair in Electrical Engineering in 1982. He has remained at and loved the University of Notre Dame for over 40 years. Mike also held a number of consulting jobs throughout his career. Most notably, he consulted with the Energy Controls Division of Allied Bendix Aerospace from 1976 to 1988 and the North American Operations branch of the Research and Development Laboratory of General Motors Corporation for a decade (1984-1994).

Rational Function Systems and Electrical Networks with Multi-parameters Kai-Sheng Lu, 2012. To overcome the problems of system theory and network theory over real field, this book uses matrices over the field $F(z)$ of rational functions in multi-parameters describing coefficient matrices of systems and networks and makes systems and network description over $F(z)$ and researches their structural properties: reducible condition of a class of matrices over $F(z)$ and their characteristic polynomial type 1 matrix and two basic properties: variable replacement conditions for independent parameters, structural controllability and observability of linear systems over $F(z)$, separability, reducibility, controllability, observability, and structural conditions of networks over $F(z)$ and so on. This book involves three subjects: systems, networks, and matrices over $F(z)$, which is an achievement of interdisciplinary research. *CONTROL SYSTEMS, ROBOTICS AND AUTOMATION - Volume III* Heinz Unbehauen, 2009-10-11. This Encyclopedia of Control Systems, Robotics, and Automation is a component of the global Encyclopedia of Life Support Systems (EOLSS), which is an integrated compendium of twenty-one Encyclopedias. This 22-volume set contains 240 chapters, each of size 5000-30000 words, with perspectives, applications, and extensive illustrations. It is the only publication of its kind, carrying state-of-the-art knowledge in the fields of Control Systems, Robotics, and Automation, and is aimed by virtue of the several applications at the following five major target audiences: University and College Students, Educators, Professional Practitioners, Research Personnel, and Policy Analysts, Managers, and Decision Makers, and NGOs.

Handbook of Control Systems Engineering Louis C. Westphal, 2012-12-06. This book is a revision and extension of my 1995 Sourcebook of Control Systems Engineering. Because of the extensions and other modifications, it has been retitled *Handbook of Control Systems Engineering*, which it is intended to be for its prime audience: advanced undergraduate students, beginning graduate students, and practising engineers needing an understandable review of the field or recent developments which may prove useful. There are several differences between this edition and the first. Two new chapters on aspects of nonlinear systems have been incorporated. In the first of these, selected material for nonlinear systems is concentrated on four aspects: showing the value of certain linear controllers, arguing the suitability of algebraic linearization, reviewing the semi-classical methods of harmonic balance, and introducing the nonlinear change of variable technique known as feedback linearization. In the second chapter, the topic of variable structure control, often with sliding mode, is introduced. Another new chapter introduces discrete event systems, including several approaches to their analysis. The chapters on robust control and intelligent control have been extensively revised. Modest revisions and extensions have

also been made to other chapters often to incorporate extensions to nonlinear systems

A New Steering System Control Design for Autonomous Passenger Vehicles Vivan Govender, 2024-06-12 This work investigates the challenge of steering system positional control with a specific view to autonomous driving Positional control of steering systems has until now been under researched to meet the performance scope of fully autonomous driving As such a parallel axis steering gear found in luxury vehicles is the target system for this work The focus of this thesis is a model based approach to steering control Moreover these models are developed using measurement based techniques thereby determining the main factors reproducing the system behaviour

Vibration Control of Active Structures A. Preumont, 2006-04-11 My objective in writing this book was to cross the bridge between the structural dynamics and control communities while providing an overview of the potential of SMART materials for sensing and actuating purposes in active vibration control I wanted to keep it relatively simple and focused on systems which worked This resulted in the following i I restricted the text to fundamental concepts and left aside most advanced ones i.e. robust control whose usefulness had not yet clearly been established for the application at hand ii I promoted the use of collocated actuator sensor pairs whose potential I thought was strongly underestimated by the control community iii I emphasized control laws with guaranteed stability for active damping the wide ranging applications of the IFF are particularly impressive iv I tried to explain why an accurate prediction of the transmission zeros usually called anti resonances by the structural dynamicists is so important in evaluating the performance of a control system v I emphasized the fact that the open loop zeros are more difficult to predict than the poles and that they could be strongly influenced by the model truncation high frequency dynamics or by local effects such as membrane strains in piezoelectric shells especially for nearly collocated distributed actuator sensor pairs this effect alone explains many disappointments in active control systems

Dynamic Modeling and Active Vibration Control of Structures Moon Kyu Kwak, 2021-08-14 This book describes the active vibration control techniques which have been developed to suppress excessive vibrations of structures It covers the fundamental principles of active control methods and their applications and shows how active vibration control techniques have replaced traditional passive vibration control The book includes coverage of dynamic modeling control design sensing methodology actuator mechanism and electronic circuit design and the implementation of control algorithms via digital controllers An in depth approach has been taken to describe the modeling of structures for control design the development of control algorithms suitable for structural control and the implementation of control algorithms by means of Simulink block diagrams or C language Details of currently available actuators and sensors and electronic circuits for signal conditioning and filtering have been provided based on the most recent advances in the field The book is used as a textbook for students and a reference for researchers who are interested in studying cutting edge technology It will be a valuable resource for academic and industrial researchers and professionals involved in the design and manufacture of active vibration controllers for structures in a wide variety of fields and industries including the

automotive rail aerospace and civil engineering sectors Nonlinear Filtering Jitendra R. Raol, Girija Gopalratnam, Bhekisipho Twala, 2017-07-12 Nonlinear Filtering covers linear and nonlinear filtering in a comprehensive manner with appropriate theoretic and practical development Aspects of modeling estimation recursive filtering linear filtering and nonlinear filtering are presented with appropriate and sufficient mathematics A modeling control system approach is used when applicable and detailed practical applications are presented to elucidate the analysis and filtering concepts MATLAB routines are included and examples from a wide range of engineering applications including aerospace automated manufacturing robotics and advanced control systems are referenced throughout the text **A Unified Algebraic Approach To Control Design** Robert E. Skelton, T. Iwasaki, K. Grigoriadis, 2017-11-22 This text deals with the most fundamental deficiency of modern theory control the lack of an easily applicable method for the design of low order controllers It shows that solutions to many different problems in control all reduce to the same linear algebra problem It employs matrix equalities and matrix inequalities in the solutions of fixed order control and also provides computational algorithms *University of Michigan Official Publication* University of Michigan, 1988 Each number is the catalogue of a specific school or college of the University *Feedback Control for Computer Systems* Philipp K. Janert, 2013-09-19 How can you take advantage of feedback control for enterprise programming With this book author Philipp K Janert demonstrates how the same principles that govern cruise control in your car also apply to data center management and other enterprise systems Through case studies and hands on simulations you ll learn methods to solve several control issues including mechanisms to spin up more servers automatically when web traffic spikes Feedback is ideal for controlling large complex systems but its use in software engineering raises unique issues This book provides basic theory and lots of practical advice for programmers with no previous background in feedback control Learn feedback concepts and controller design Get practical techniques for implementing and tuning controllers Use feedback design patterns for common control scenarios Maintain a cache s hit rate by automatically adjusting its size Respond to web traffic by scaling server instances automatically Explore ways to use feedback principles with queueing systems Learn how to control memory consumption in a game engine Take a deep dive into feedback control theory *Applied Mechanics Reviews* , 1968 **Control Theory for Physicists** John Bechhoefer, 2021-04 Bridging the basics to recent research advances this is the ideal learning and reference work for physicists studying control theory *Electromechanical Systems and Devices* Sergey Edward Lyshevski, 2008-03-26 Students entering today s engineering fields will find an increased emphasis on practical analysis design and control They must be able to translate their advanced programming abilities and sound theoretical backgrounds into superior problem solving skills Electromechanical Systems and Devices facilitates the creation of critical problem solvin

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