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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 (OKSID) using time domain input-output data (Peters 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

**Louis C. Westphal**



## Frequency Domain And State Space Methods For Linear Systems:

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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

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 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

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**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, Bhakisipho 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      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      **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

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