

Recent Advances in Subspace System Identification and Monitoring: Linear, Nonlinear, Closed-Loop, and Optimal With Applications

A pre-conference workshop June 8-9, attend either or both days,
Held at 2009 American Control Conference, St. Louis, MO

Instructor

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1. Course Overview

This workshop presents a first principles development of subspace system identification (ID) using a fundamental statistical approach. This includes basic concepts of reduced rank modeling of ill-conditioned data to obtain the most appropriate statistical model structure and order using optimal maximum likelihood methods. These principles are first applied to the well developed subspace ID of linear systems; and using recent results, it is extended to closed-loop linear systems and then general nonlinear closed-loop systems.

The fundamental statistical approach gives expressions of the multistep likelihood function for subspace identification of both linear and nonlinear systems. This leads to direct estimation of the parameters using singular value decomposition type methods that avoid iterative nonlinear parameter optimization. The result is statistically optimal maximum likelihood parameter estimates and likelihood ratio tests of hypotheses. The parameter estimates have optimal Cramer-Rao lower bound accuracy, and the likelihood ratio hypothesis tests on model structure, model change, and process faults produce optimal decisions. Comparisons are made between various system identification methods including subspace, prediction error, and maximum likelihood.

The extension to general nonlinear systems determines optimal nonlinear functions of the past and future using the theory of maximal correlation. This gives the nonlinear canonical variate analysis. New results show that to avoid redundancy and obtain gaussian variables, it is necessary to determine independent canonical variables that are then used in the likelihood function evaluation. This gives a complete likelihood theory for general nonlinear stochastic system with continuous dynamics and possibly feedback.

These new results greatly extend the possible applications of subspace ID to closed-loop linear and nonlinear systems for monitoring, fault detection, control design, and robust and adaptive control. The precise statistical theory gives tight bounds on the model accuracy that can be used in robust control analysis and design. Also precise distribution theory is available for tests of hypotheses on model structure, process changes and faults. Potential applications include system fault detection for control reconfiguration, autonomous system monitoring and learning control, and highly nonlinear processes in emerging fields such as bioinformatics and nano technology. Applications are discussed to monitoring and fault detection in closed-loop chemical processes, identification of vibrating structures under feedback, online adaptive control of aircraft wing flutter, identification of the chaotic Lorenz attractor, and identification and monitoring of nonlinear automotive engines.

2. Intended Audience

The intended audience includes practitioners who are primarily interested in applying system identification and monitoring techniques, engineers who desire an introduction to the concepts of subspace system identification and maximum likelihood monitoring, and faculty members and graduate students who wish to pursue research into some of the more advanced topics. Attendees may register for either day as a 1-Day Workshop, or both days as a 2-Day Workshop (the first day has been previously attended by hundreds of ACC attendees).

3. Course Outline

DAY ONE - LINEAR SYSTEMS WITH FEEDBACK

8:30-9:15 OVERVIEW OF SUBSPACE SYSTEM IDENTIFICATION

- Approaches and Algorithms
- Positivity, Stability, Accuracy, Computation

9:15-10:00 RANK OF A STOCHASTIC DYNAMIC SYSTEM

- Statistical Rank - Canonical Variate Analysis (CVA)
- Rank as Minimal State Order

Break

10:30-11:15 SUBSPACE MAXIMUM LIKELIHOOD ESTIMATION

- Multistep Likelihood Function
- State Space Regression Equations

11:15-12:00 STATISTICAL MODEL ORDER/STRUCTURE SELECTION

- Kullback Information and Akaike Information
- Accuracy of Estimated Model

Lunch Break

1:00-2:00 COMPARISON OF ALTERNATIVE SYSTEM IDENTIFICATION APPROACHES

- Model Structure Selection and Parameter Estimation
- Computational Issues and Software

2:00-2:45 OPTIMAL IDENTIFICATION OF I/O AND CLOSED-LOOP SYSTEMS

- Removing Effect of Future Inputs
- Model Nesting and Sufficient Statistics

3:15-4:00 PROCESS MONITORING USING CVA

- Low Rank Process Characterization by CVA
- Testing Hypotheses of Process Change

Break

4:00-4:45 PROCESS MONITORING APPLICATIONS

- Tennessee Eastman Challenge Problem
- Comparison with SPC and PCA Methods

4:45-5:30 IDENTIFICATION AND CONTROL APPLICATIONS

- Vibrating Structures
- On-line Adaptive Control of Aircraft Wing Flutter

DAY TWO - NONLINEAR AND MAXIMUM LIKELIHOOD ASPECTS

8:30-9:15 OVERVIEW OF NONLINEAR SYSTEM IDENTIFICATION METHODS

- Hammerstein and Wiener Systems
- Nonlinear State Space Models

9:15-10:00 NONLINEAR CANONICAL VARIATE ANALYSIS

- Nonlinear Functions of Past and Future
- Multivariate Reduction by Maximal Correlation

Break

10:30-11:15 MAXIMAL CORRELATION AND PROJECTION

- Definition and Properties
- Outline of Function Space Concepts

11:15-12:00 MINIMAL STATE RANK AND INDEPENDENT CVA

- Redundancy Problem with CVA
- Optimal Transformations to Gaussian Variables

Lunch Break

1:00-2:00 LIKELIHOOD FUNCTION FOR NONLINEAR SYSTEMS

- Multistep Likelihood
- Optimality of Independent CVA

2:00-2:45 OPTIMALITY IN CLOSED LOOP

- Remove Future Inputs with NARX
- Model Nesting and Nonlinear Regression

3:15-4:00 COMPARISON WITH OTHER METHODS

- Neural Networks, Statistical Learning
- Support Vector Machines

Break

4:00-4:430 COMPUTATIONAL METHODS

- Alternating Conditional Expectation (ACE)
- Kernel based Computation

4:30-5:00 LORENTZ ATTRACTOR IDENTIFICATION

- Nonlinear Dynamics and Noise
- Computation and Identification Accuracy

5:00-5:30 AUTOMOTIVE ENGINE IDENTIFICATION & MONITORING

- Identification of Global Nonlinear SS Model
- Monitoring System Failures & Changes

4. Course Instructor

Dr. Larimore received his Ph.D. and M.S. degrees in Statistics from George Washington University, and did his dissertation in the area of time series analysis. He has thirty years experience in the development of statistical methods with applications to dynamical processes and time series data. He is founder and president of Adaptics Inc, and has developed the ADAPT_x software for the automatic time series analysis and modeling of dynamical processes. Dr. Larimore has done fundamental work in extending the canonical variate analysis method to the analysis of time series data including the publication of the first paper on subspace system identification.

Dr. Larimore has applied these methods to financial and econometric data, modeling and control of vibrating structures, detection and modeling of brain waves, and modeling and control of chemical and industrial processes. He has more than 70 published papers, and has organized numerous sessions at professional meetings. He has given workshops on Automated Multivariable Time Series Analysis and System Identification at several dozen conferences of various professional societies as well as at a number of corporations. He is a member of the American Statistical Association, Institute of Electrical and Electronic Engineers, and the Society for Industrial and Applied Mathematics.

The 1994 Statistics in Chemistry Award given by the Chemometrics Committee of the American Statistical Association was awarded to Dr. Larimore of Adaptics, Inc, in collaboration with Professors Duncan A. Mellichamp and Dale E. Seborg and their former graduate students Dr. Charles Schaper and Dr. Andreas H. Kemna of the Department of Chemical and Nuclear Engineering, at the University of California at Santa Barbara. The award is for the outstanding collaboration between statisticians and chemists in an industrial setting as judged by innovation and impact on the field.