Identification of Parameter Varying and Nonlinear Systems Via Subspace Methods

A proposal for a pre-conference workshop June 28 or 29,
Held at 2010 American Control Conference, Baltimore, Maryland

Instructor
Wallace E. Larimore; Adaptics, Inc, Email: larimore@adaptics.com

1. Course Overview

In the last two decades, the control and modeling of parameter-varying and nonlinear systems has advanced considerably. While very significant work in model identification for these systems has been done, major difficulties in accuracy and computation remain. In this workshop, major recent developments in system identification for parameter-varying and nonlinear systems using subspace methods are developed.

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 of canonical variate analysis (CVA) 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 linear methods are extended to linear parameter-varying (LPV), bilinear, and general nonlinear parameter-varying systems, where the parameter-varying functions depend on the system operating point. A major tool is to represent these systems as linear time-invariant (LTI) systems with nonlinear feedback. The LTI parameters are constant over changing operating points. For example, this allows for the identification of constant underlying structural stiffness parameters while wing flutter dynamics vary with speed and altitude operating point variables. The LTI nonlinear feedback form is related to recent results in global control design and gain scheduling for LPV systems.

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.

Preprint submitted to 2010 American Control Conference.
Received November 30, 2009.

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 system identification and maximum likelihood monitoring, and faculty members and graduate students who wish to pursue research into some of the more advanced topics.

3. Course Outline

8:30-9:00 OVERVIEW OF WORKSHOP
- LTI Feedback Representations of Linear, LPV and Nonlinear Systems
- Subspace System Identification, State Estimation, and Feedback

LINEAR SUBSPACE SYSTEM IDENTIFICATION

9:00-9:30 RANK OF A STOCHASTIC DYNAMIC SYSTEM
- Statistical Rank - Canonical Variate Analysis (CVA)
- Rank as Minimal State Order

9:30-10:00 SUBSPACE MAXIMUM LIKELIHOOD ESTIMATION
- Multistep Likelihood Function
- State Space Regression Equations

Break

10:15-10:45 STATISTICAL MODEL ORDER/STRUCTURE SELECTION
- Kullback Information and Akaike Information
- Accuracy of Estimated Model

10:45-11:30 OPTIMAL IDENTIFICATION OF I/O AND CLOSED-LOOP SYSTEMS
- Removing Effect of Future Inputs
- Model Nesting and Sufficient Statistics

11:30-12:00 PROCESS MONITORING USING CVA
- Low Rank Process Characterization by CVA
- Testing Hypotheses of Process Change

Lunch Break

IDENTIFICATION OF LTI SYSTEMS WITH NONLINEAR FEEDBACK

1:00-1:45 OVERVIEW OF NONLINEAR SYSTEM MODELS
- NARX, Hammerstein and Wiener Systems
- Nonlinear State Space Models – LPV, Bilinear, NLPV
- Carleman Bilinear Representation of Polynomial Systems

1:45-2:15 LTI NONLINEAR FEEDBACK REPRESENTATION
- LPV Models Interpolate Across Operating Conditions
- Bilinear Form Reduces to Linear Time-varying Case
- Relationship to Global Control Design and Gain Scheduling

2:15-3:00 NONLINEAR SYSTEM ID METHODS
- Gradient Maximum Likelihood
- Expectation-Maximization
- Direct Subspace Identification
- Iterative Subspace Identification

Break

Preprint submitted to 2010 American Control Conference.
Received November 30, 2009.

IDENTIFICATION AND MONITORING APPLICATIONS

3:15-3:45 1:00-1:30 PROCESS MONITORING APPLICATIONS
- Tennessee Eastman Challenge Problem
- Comparison with SPC and PCA Methods

3:45-4:30 1:30-2:15 IDENTIFICATION AND CONTROL APPLICATIONS
- Vibrating Structures
- On-line Adaptive Control of Aircraft Wing Flutter

4:30-5:30 NONLINEAR SYSTEM ID AND FAILURE MONITORING APPLICATIONS
- Lorenz Attractor
- Identification of Automotive Engines
- Failure Diagnosis of Automotive Engines
- Identification of NLPV Aerodynamic Models

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 ADAPTx 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 professions 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.

Preprint submitted to 2010 American Control Conference.
Received November 30, 2009.