ONE-DAY TUTORIAL WORKSHOP

AUTOMATED MULTIVARIABLE SYSTEM IDENTIFICATION: BASIC PRINCIPLES WITH CONTROL AND MONITORING APPLICATIONS

Wallace E. Larimore; Adaptics, Inc,
Dale E. Seborg; University of California, Santa Barbara

Sponsored by the 2003 American Control Conference
June 4-6, 2003, Denver, Colorado

Over the past several years, computational methods and software have been developed to reliably identify system dynamics from input/output data with optimal statistical accuracy. These automatic methods apply to a very general class of linear systems including multi-input/multi-output, state and measurement noise disturbances, unknown feedback, unknown state order, and possibly unstable or highly resonant dynamics. Existing methods for high accuracy identification such as Box/Jenkins and prediction error methods are problematic in that they are both computationally unreliable and involve a tedious toolbox approach requiring graduate level training.

The automatic methods presented in this workshop are fundamentally different and involve direct determination of the system states, i.e. system rank, using stable singular value decomposition (SVD) computations. Optimal rank selection based on canonical variate analysis (CVA) is related to partial least squares (PLS), principal component analysis (PCA), and subspace system identification methods. Statistical order selection methods are described that give optimal determination of state order. The state space dynamics are determined by simple multivariate regression. The concepts are presented in a direct first principles way that is appropriate for advanced undergraduate and graduate curriculum so that automated system identification can be made much more accessible to those in most need of using it.

This advance in system identification has major implications for analysis, system monitoring, and design and implementation of control systems for many applications including aerospace, automotive, and chemical and industrial processes. For process monitoring, CVA provides powerful new methods for the detection and analysis of changes in colinear multivariable processes. For control system implementation, CVA provides high accuracy multivariable models even in the presence of unknown system feedback. CVA provides a starting point for robust control design since accuracy confidence bands on the identified model are automatically provided. Since the computation is completely automatic, it is ideal for online and adaptive control applications. A number of such applications are presented including an industrial recovery boiler, stirred tank reactor, autothermal reactor, distillation column, change monitoring for the Tennessee Eastman Challenge Problem, and online adaptive control in a wind tunnel test of unstable aircraft wing flutter. Automated system identification methods are compared with alternative approaches in terms of model types considered, required user knowledge, computational requirements and reliability, and results of model fitting with simulated and real data sets.

The intended audience includes practitioners who are primarily interested in applying system identification techniques, engineers who desire an introduction to the concepts of automated system identification, and faculty members and graduate students who wish to pursue research into some of the more advanced topics in automated system identification.

WORKSHOP OUTLINE

* **Overview of System Identification Methods**
  - Regression and Latent Variables (PCA, PLS)
  - Box/Jenkins (ARIMAX) and Prediction Error Methods
  - State Space Models and Subspace System Identification
  - Parameter Estimation and Fitting Models to Data
  - Model Structure Selection and Diagnostics

* **Rank of a Dynamical System and State Estimation**
  - Linear Equation Rank and the SVD
  - Statistical Rank - Canonical Variables and GSVD
  - Rank and States of an Input-Output System
  - Rank and States of a Dynamical Random Process

* **Model Order Selection Based on Statistical Criteria**
  - Kullback Information and Model Approximation
  - Akaike, Schwarz, Rissanen, and Hannan-Quinn Criteria
  - Application of Model Comparison and Order Selection
  - Accuracy of Estimated Model

* **Model Parameter Estimation and Filtering**
  - State Space Regression Equations
  - Innovations, Echelon, and ARMAX Forms
  - Integrating and Unstable Systems
  - Kalman Filter and Multistep Prediction

* **Comparison of Alternative System Identification Approaches**
  - Model Types Considered
  - Model Structure Selection and Parameter Estimation
  - Computational Issues and Software
  - Simulation Examples

* Identification with Unknown Delays and Feedback
  - Identification of System Delay Structure

- Open-loop Identification with Closed-loop Data
- Identification of Feedback Structure
- Input Excitation Requirements and Design

* **Process Monitoring using CVA**
  - Low Rank Process Characterization by CVA
  - Testing Hypotheses of Process Change
  - Determining Characteristics of Process Change
  - Control System Performance Monitoring

* **Process Monitoring Applications**
  - Stirred-tank Reactor
  - Tennessee Eastman Challenge Problem
  - Comparison of Open- and Closed-loop Performance
  - Comparison with SPC and PCA Methods

* **Identification and Control Applications**
  - Distillation Column
  - Chemical Reactors
  - Industrial Recovery Boiler
  - Vibrating Structures
  - On-line Adaptive Control of Aircraft Wing Flutter