Invited Session Proposal:
New Developments in Closed-Loop Identification

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1 Session Organizers

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2 Description of the topic

Closed loop identification has always been recognized to be of primary importance and has been object of intense research since the late sixties. It is recognized that most of the times feedback cannot be removed for various reasons among which: (i) it may be intrinsic in the physical mechanism generating the data or (ii) data may come from an industrial plant where feedback loops cannot be open due to safety or production quality reasons or (iii) the physical mechanism might be too complex and may not be easily manipulated (think for instance to a communication network). Another reason for performing identification in closed-loop comes from the need to design experiments which guarantee a desired level of uncertainty in certain frequency bands. This has proven to be particularly useful in *Identification for Control*.

The renewed interest for this subject in the recent years is due to a multiplicity of factors; on the "practical side" we mention the increased interest from various application areas (process control, control of networks and so on). Modern industrial applications often involve large plants described by tens of input and output variables and it is fair to say that these applications could only be tackled using the recently developed *subspace methods* (see e.g. contributions 5. and 6. below). On the other hand, there is a recent body of results concerning subspace methods in closed loop which have, for the first time, made these methods applicable to experiments in closed loop. There has recently been quite a lot of synergy between theory and applications.

Nowadays researchers are well aware of the issues and difficulties arising when performing subspace identification using data collected in closed loop. The contributions of this session will touch upon several aspects of these, ranging from theory to practice.

The contribution by K. Onodera, G. Emoto, and S. J. Qin deals with new algorithms for subspace identification ("*A New Subspace Identification Method for Closed Loop Systems*"); then S. J. Qin and L. Ljung will discuss the role of certain user choices in closed loop subspace identification ("*On the Role of Future Horizon in Closed-Loop Subspace Identification*"). The contribution by A. Chiuso and G. Picci ("*Estimating the Asymptotic Variance of Closed Loop Subspace Estimators*") will try to bridge theory and practice showing that the recent theoretical results on the asymptotic properties of closed loop subspace estimators can be effectively used in practice where one needs to compute variance using data alone.

The last three contributions will deal with various applications of closed loop identification. They will range from new application areas such as the paper "*Closed loop aspects of fluid flow model identification in congestion control*" by K. Jacobsson and H. Hjalmarsson which addresses identification problems which arise in network control, to more classical areas. In particular the paper "*Subspace Identification of Gasifying and Direct Melting Plant for Control* " by H. Ase, K. Takaba and T. Katayama shall be concerned with the application of a subspace procedure to (closed-loop) identification of a real plant, and will include control design based in the identified model. Last but not least the paper by H. Zhao and M. Harmse ("*Subspace Identification in Industrial APC Applications – A Review of Recent Progress and Industrial Experience*") will report experiences from industry (*Aspen Technology, Inc.*) on identification in Advanced Process Control (APC). In particular issues related to closed loop identification will be discussed.

The contributors are world-renowned experts in the areas of identification and process control; contributions from industry (*Aspen Technology, Inc.* and *Mitsubishi Chemical Engineering Corporation*) are also included which confirm the strong interplay between theory and practice in this area.

3 List and description of the proposed session contributions

1. *A New Subspace Identification Method for Closed Loop Systems*
   Koichi Onodera, Genichi Emoto, and S. Joe Qin

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   Paper contibution:

   In this paper we present a new subspace identification method applicable to closed-loop data. First, Kalman predictor Markov parameters in a framework of ARX modeling with high order are obtained. These parameters are made available for subspace identification to help the estimation of the Hankel matrix which consists of the estimated predictor Markov parameters. To estimate the observer matrices, eigensystem realization algorithm (ERA) with weightings related to canonical correlation analysis (CCA) is applied to the Hankel matrix. System matrices are easily derived from the estimated observer matrices. We then demonstrate the effectiveness of the proposed algorithm via simulated and industrial closed loop data. Keywords: subspace identification; Kalman predictor Markov parameters; eigensystem realization algorithm (ERA); canonical correlation analysis (CCA); observer/Kalman filter identification (OKID);

2. *On the Role of Future Horizon in Closed-Loop Subspace Identification*
   S. Joe Qin and Lennart Ljung

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   Paper contibution:

   Closed loop subspace identification has become the focus of interest with several recent development. Notably are the innovation estimation approach (Qin and Ljung, 2003), the state space approach with ARX pre-estimates (SSARX, Jansson, 2003), and the whitening filter approach (Chiuso and Picci, 2004). All these approaches use an extended future horizon to form the projection or regression in which an observable subspace is extracted. Yet there are other methods such as OKID of (Phan et al. 1992) and that of Ljung and McKelvey (1996) that do not use an extended horizon in the projection or regression step. Instead, a single high order ARX was used. A natural question is whether the future horizon is necessary and if so what role does it play in these steps. In this paper we investigate the role of the future horizon using the whitening filter approach of (Chiuso and Picci, 2004), which works for both open loop and closed-loop data. We conclude that the role of future horizon in this algorithm is merely extending the order of a bank of already high order ARX models. The difference from a single ARX model is insignificant if the ARX order or past horizon is sufficiently high. The role of future horizon is mainly in the model reduction step where it serves to elevate the ARX model order. We complement the analysis with simulations.

3. *Estimating the Asymptotic Variance of Closed Loop Subspace Estimators*
   Alessandro Chiuso and Giorgio Picci

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   Paper contibution:

   Subspace identification for closed loop systems has been recently studied by several authors. Recent results are available which express the asymptotic variance of the estimated parameters (and hence of any system invariant) as a function of the “true” underlying system parameters and of certain conditional covariance matrices.

   When it comes to using these formulas in practice one is faced with the problem of computing an estimator for the variance from input-output data alone.

   In this paper this problem is discussed, an algorithm which computes an estimate of the variance from data is proposed and it is shown through some simple simulation examples how this estimate behaves as compared both to the “true” asymptotic variance and to its Monte Carlo estimate.

4. *Closed loop aspects of fluid flow model identification in congestion control*
   Krister Jacobsson and Håkan Hjalmarsson

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   Paper contibution:

   Fluid flow models have turned out to be instrumental for analysis and synthesis of primal/dual congestion control algorithms which rely on aggregated information from a network path. In particular stability has been analyzed using such models. In network congestion control, validation experiments will with necessity be performed in closed loop since the communication protocol has to be active. Instructions on how such experiments should be carried out in practice has until now been lacking in the literature. Departing from the theory of modeling for control, we refine the fluid flow model by augmenting the customary model of transport latencies, link price and source control with estimator dynamics and sampling properties. The impact of cross-traffic and changes in network configuration is incorporated as well. Furthermore, we analyze how the network should be excited when validating such models. The resulting identification framework is used for validating the derived model using packet-level experimental data from NS-2 simulations.

5. *Subspace Identification of Gasifying and Direct Melting Plant for Control*
   Hajime Ase, Kiyotsugu Takaba and Tohru Katayama

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Paper contibution:

This paper deals with the subspace identification of a high temperature gasifying and direct melting furnace coupled with a boiler-turbine plant for power generation. Based on preliminary statistical analysis using data observed under closed-loop operation, we model the system as a multivariable linear system with four exogenous inputs (refuse-derived fuel feed rate, coke feed rate, layer height, sub-tuyere air flow rate), two control inputs (combustion air flow rate and recirculation gas flow rate) and three outputs (secondary chamber temperature, oxygen concentration and exhaust gas flow rate). The goal of this paper is to develop a discrete-time state-space model for the gasifying and direct melting plant by using the two-stage orthogonal decomposition (ORT) method presented at the IFAC Prague World Congress (2005). Following a brief description of the two-stage ORT method as applied to the present furnace system, we show models obtained by using closed loop data. Also, some simulation results with a newly designed anti-windup controller are included. This work will help to improve the existing furnace controller.

6. *Subspace Identification in Industrial APC Applications – A Review of Recent Progress and Industrial Experience*
Hong Zhao and Michael Harmse

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Paper contibution:

The Subspace identification approach was only introduced into industrial advanced process control (APC) applications around 5 years ago. Although the method has received a lot of attentions from academia for a considerable period of time, the subspace identification algorithm only became available as part of a commercially available industrial APC package in 2000. After five years of industrial use, several issues were identified that required algorithmic improvements, the subspace identification technology has been widely accepted and is now used in numerous industrial APC projects. We have found that multi-variable constrained plant testing technology and subspace identification technology works in a synergistic way to substantially reduce plant test duration. Improved identification efficiency from shorter but richer data sets results in better model accuracy, and consequently project cost have reduced significantly over the past 4 years, making it possible to deploy APC on process units that would not have yielded a suitable return on investment before. For example, plant testing and model identification could be completed in 48 hours on a recent project, a new world record. In addition, a complex Fluid Catalytic Cracking (FCC) unit with 35 manipulated variables (MVs) and 94 controlled variables (CVs) have been reportedly been completed in only 4 days. Using the traditional manual step testing and FIR model identification approach, it would have taken 3-4 weeks to finish the project.