# Workshop on Data-driven Modeling Methods and Applications

Leuven, July, 14–15, 2014

## Abstracts

## Session 1: Optimization Methods

### 10:20 – 11:00, 14th, July

**Global Piecewise Linear Optimization Algorithm for Data-driven Modeling**
*Shuning Wang, Department of Automation, Tsinghua University*

In this talk, we first explain that several classical issues in data-driven modeling can be expressed as a problem of minimizing a concave piecewise linear function over a polyhedron, then introduce a new approach for finding a global solution of such problem. The approach to be reported can be regarded as an extension of the newly proposed algorithm, called hill-detouring, for the same problem. After briefly reviewing the basic steps of the hill-detouring algorithm, and analyzing its shortcoming, we present the major measures adopted in the new approach. These measures may effectively overcome the shortcoming of the current hill-detouring process; hence make the extended algorithm have better performance.

### 11:00 – 11:20, 14th, July

**Frank-Wolfe Algorithms for SVMs: Complexity and Practical Strategies**
*Emanuele Frandi, Department of Electrical Engineering, KU Leuven*

Frank-Wolfe algorithms are classical first-order methods for solving concave optimization problems on the unit simplex and other convex polyhedra. The last years have seen a surge of interest in these procedures from the machine learning community, as they allow to efficiently compute approximate solutions with a certifiable sparsity at an overall cost proportional to the total number of variables. However, the complexity of the standard Frank-Wolfe iteration can still be prohibitive on large problems. This is often the case, for example, in SVM learning. As such, some form of stochastic/randomized iteration, e.g. to select a fixed-size set of variables at each optimization step, is essential in practice. We discuss some open problems related to this issue, and present a few preliminary experimental results.

### 11:20 – 11:40, 14th, July

**Robust Low Rank Tensor Completion with Regularized Redescending M-estimator**
*Yuning Yang, Department of Electrical Engineering, KU Leuven*

Arising from real-world applications such as image/video processing, intelligent transportation systems as well as pattern recognition, the problem of recovering data with certain low rank structure from incomplete observations can be formulated as low rank tensor completion problems. Since real-world data might be contaminated by sparse gross errors, robust techniques are demanded. However, existing approaches may not be very robust to outliers. To address this problem, we employ redescending

M-estimators, which has been introduced in robust statistics, into tensor completion problems. Redescending M-estimators bring us robustness, whereas they also lead to nonconvexity. Nevertheless, by verifying the Lipschitz continuity, we can solve our approaches by block coordinate descent type methods and prove the convergence of the methods. The proposed methods produce satisfactory results, as demonstrated by experiments on synthetic as well as real data sets.

### 11:40 – 12:00, 14th, July

**Coordinate Descent Algorithm for Ramp Loss Linear Programming Support Vector Machines**
*Xiangming Xi, Department of Electrical Engineering, KU Leuven*

In order to control the effects of outliers in training data and get sparse results, Huang et al. proposed the ramp loss linear programming support vector machine (ramp-LPSVM). This combination of l1 regularization and ramp loss not only limits the effects of outliers with a maximal penalty, but also leads to the sparsity of parameters in decision functions. However, due to its non-convexity, the computational cost to achieve a satisfying solution is often expensive. In this presentation, by exploiting the theoretical properties of ramp-LPSVM, we propose a modified coordinate descent algorithm (CDA). CDA is an efficient algorithm for multi-variable optimization problems, which optimizes one single entry of the independent variable each time. In this way, a multi- variable problem is reduced to a series of one-variable subproblems. Besides, such subproblems of ramp-LPSVM also enjoy piecewise linearity. Considering the special form of ramp loss functions, we propose an efficient algorithm to deal with its non-convexity and make it applicable to large-scale ramp-LPSVM problems. In addition to the theoretical analysis on convergence of the modified coordinate descent algorithm, numerical experiments have also been carried out on benchmark data sets. The results confirm its outstanding performances in classification accuracy, computational efficiency and capability of dealing with large-scale problems.

## Session 2: Modeling and Control

### 14:00 – 14:40, 14th, July

**Model Structure Learning for LPV and Nonlinear System Identification using LS-SVMs**
*Roland Toth, Control Systems Group, Eindhoven University of Technology*

In identification of Linear Parameter-Varying (LPV) and general nonlinear systems (NL), a number of center problems evolve around the posed priors on the assumed model class and efficient capturing and parameterization of the nonlinearities. For example, accurate parametric identification of LPV systems requires an optimal prior selection of a set of functional dependencies for the parameterization of the model coefficients on a so-called scheduling signal. Inaccurate selection leads to structural bias while over-parameterization results in a variance increase of the estimates. This corresponds to the classical bias-variance trade-off, but with a significantly larger degree of freedom and sensitivity in the LPV case. Hence, it is attractive to estimate the underlying model structure of LPV systems based on measured data, i.e., to learn the underlying dependencies of the model coefficients together with model orders.
In this talk, a brief overview will be given on some recent developments of model structure learning in the LPV and NL context, focusing on the use of l1-regularization based least-squares support vector machines (SVM's) and an instrumental SVM to handle general noise conditions.

## 14:40 – 15:00, 14th, July

**Applications of Data-driven Modeling on Control and Optimization of Distillation Process**
*Wenxiang Lu, Department of Automation, Tsinghua University*

Distillation process is the most widely used separation process in petroleum chemical industries and other chemical industries. Large inertia delay exists in the response of product quality in a distillation process, especially a high purity distillation process. It is difficult to ensure the product quality smoothness and operation optimization to achieve the maximum production profit. Based on the analyzed conclusion that split ratio and separation factor are the key factors of maintaining the stability of product quality, a novel stable quality control method is proposed. Furthermore, an integrated control and optimization strategy and the overall framework of implementation are presented based on the stable quality control method, dynamic feedback optimization and steady-state optimization. In this strategy, both control model and dynamic feedback optimization model are using dynamic model, which is constructed with model identification method. And the steady-state optimization model is using steady-state one, which is built with RBF NN or AHH, etc. Relatively, the AHH model shows advantages on modeling accuracy, model complexity, and computation power of optimization especially.

## 15:00 – 15:20, 14th, July

**Combining Regularization and SVD Truncation for Impulse Response Modeling**
*Anna Marconato, Depart. of Fundamental Electricity and Instrumentation, Vrije Universiteit Brussel*

In this work we consider the estimation of FIR models, in the situation where the system is excited with a colored noise input. For this problem, the application of regularization techniques has recently proven beneficial. Low-rank approximation methods based on the truncated SVD also lead to reduced complexity estimates. The link between these two approaches is shown by reformulating the SVD truncation as a regularization problem given a specific choice of the regularization matrix. Moreover, the two methods are combined, to include in the prior both the assumptions about the system and the information about the coloring of the input data. The results show the advantage of these techniques for impulse response estimation.

## 15:20 – 15:40, 14th, July

**Decoupling Multivariate Functions in Block-oriented System Identification: A Linearization Approach**
*Philippe Dreesen, Depart. of Fundamental Electricity and Instrumentation, Vrije Universiteit Brussel*

Block-oriented non-linear system identification uses static non-linear multivariate functions to describe the non-linear effects in a system. The identification procedure usually results in a multiple input multiple output static mapping where in general a coupling exists between the variables (e.g., in the case of multivariate polynomials cross-terms between the input variables show up). For the sake of model interpretability, as well as to avoid the curse of dimensionality, it is desirable to find an equivalent parsimonious description where the non-linear functions are decoupled in a set of parallel single input single output mappings acting between some unknown internal variables (that are related to the inputs and outputs by means of unknown linear transformation matrices). We solve this decoupling task by means of a linearization approach: the first-order behavior of the multivariate functions is obtained in a set of operation points (this procedure is similar to constructing the small-signal model of a nonlinear element). The decoupling task then easily leads to a simultaneous matrix diagonalization problem from which the unknown linear transformations follow, as well as the internal univariate mappings.

## 16:20 – 17:00, 14th, July

**Refinery Scheduling Optimization Model and Scheduling Optimization Method based on Optimal Process Control**

*Dexian Huang, Xiaoyong Gao, Yongheng Jiang, Chao Shang*
*Department of Automation, Tsinghua University*

Due to the more and more fierce market competition, the tighter and tighter supply of the crude oil, and the development of information technology in refineries, the refinery scheduling optimization has attracted increasing attentions in both academic and industrial communities. Because that the product yields of refinery process works vary obviously with the changes of operation conditions and crude, it is very challenging to formulate accurately the schedule model and obtain an operable schedule. As existing methods either adopted mean process models, or involve unrealizable operation modes, either the schedules can not be implemented or there will be wide difference between the realized schedule and computation one. Therefore, we propose an model formulation methods and integrated scheme of the plant-wide scheduling optimization based on optimal process control. Under the unit-wide model predictive control (MPC) and real time optimization, the primary and secondary processing units can work in finite number of optimal modes, and the hydro-upgrading processing unit can be controlled to a special accuracy, we propose the multi-mode scheduling model for primary and secondary processing units, and continuous scheduling model for hydro-upgrading units. A bi-level description method is proposed to minimize the process dynamics and improve the computational efficiency. The upper level of decision-making decides the units set to be adjusted step by step from the downstream units to upstream ones and its optimal modes of units adjusted which will appoint deterministic models for scheduling optimization. The lower level solves a particular sub-scheduling problem from the upper layer. The integrated strategy is validated on a simulation platform based on UniSim Operations. Furthermore, a piecewise linear based model method is proposed to deal with strong nonlinearity of the hydro-upgrading processing units (HUPUs). To handle the so-called "curse of partitions" of the compact representations of piecewise linear model, a simplicial partition strategy with alterable intervals together with its model construction method is proposed. By the proposed piecewise linear model, the original MINLP problem involving HUPUs schedule is converted into a MILP one, which can be solved by many mature solvers. A crude oil classification based multi-model method is proposed to handle model difficulty of the secondary processing units (SPUs) caused by variable charged crudes. A classification method based on the deep belief network is presented with blending retios of different feeding crudes as inputs and the blended crude type as the output, based on the analysis of both SPUsmechanism and the current refinery operations.

**Keywords:** Scheduling optimization model, Piecewise linear model, Deep learning, Scheduling optimization , Optimal process control.

## 17:00 – 17:20, 14th, July

**Optimal Experiment Design for Nonlinear Dynamic (Bio)chemical Systems using Sequential Semidefinite Programming**

*Dries Telen, Department of Chemical Engineering, KU Leuven*

Optimal experiment design (OED) for parameter estimation in nonlinear dynamic (bio)chemical processes is discussed in the presentation. To reduce the uncertainty in an experiment, a suitable measure of the Fisher information matrix or variance-covariance matrix has to be optimized. In this work, novel optimization algorithms based on sequential semidefinite programming (SDP) are proposed. The sequential SDP approach has specific advantages over sequential quadratic programming in the context of OED. First of all, it guarantees on a matrix level a decrease of the uncertainty in the parameter estimation procedure by introducing a linear matrix inequality. Second, it allows an easy formulation of E-optimal designs in a direct optimal control optimization scheme. Finally, a third advantage of SDP is that problems involving the inverse of a matrix can be easily reformulated.

## 17:20 – 17:40, 14th, July

**Irredundant Lattice Piecewise Affine Representations and Their Applications in Explicit Model Predictive Control**

*Jun Xu[1,2], Ton J.J. van den Boom[2], and Bart De Schutter[2]*
*1. Department of Automation, China University of Petroleum (Beijing)*
*2. Delft Center for Systems and Control, Delft University of Technology*

In this presentation, we describe the continuous piecewise affine (PWA) function with the irredundant lattice PWA representations. The domain of the continuous PWA function $f$ is divided into nonoverlapping base regions $\mathbb{D}_1, \ldots, \mathbb{D}_N$, and in the base region $\mathbb{D}_i$, assume $f$ equals the affine function $\ell_{\mathrm{act}(i)}$. The base region $\mathbb{D}_i$, $1 \leq i \leq N$ is a subregion of the domain such that no other affine functions intersect with $\ell_{\mathrm{act}(i)}$ in the interior of $\mathbb{D}_i$.

The full lattice PWA representation can be expressed as $f = \max_{i\in\{1,\ldots,N\}} \{ \min_{j\in I_{\geq,i}} \{\ell_j\}\}$, in which $I_{\geq,i}$ is the set of indices of affine functions greater than or equal to $\ell_{\mathrm{act}(i)}$ in the base region $\mathbb{D}_i$. In the representation, $\min_{j\in I_{\geq,i}} \{\ell_j\}$ and $\ell_j$ are called term and literal respectively. A term $\min_{j\in I_i}\{\ell_j\}$ is called an implicant of $f$ if $\min_{j\in I_i}\{\ell_j\} \leq f$ in the whole domain, and in some base regions $\min_{j\in I_i}\{\ell_j\} \equiv f$. From this definition, the term $\min_{j\in I_{\geq,i}} \{\ell_j\}$ in the full lattice PWA representation is an implicant of $f$.

Based on the full lattice PWA representation, we derive the irredundant lattice PWA representation, i.e., no term or literal can be deleted from the expression without affecting the function value. Necessary and sufficient conditions for irredundancy are proposed. Besides, we propose necessary and sufficient conditions for replacing the original implicants with simpler implicants. An algorithm for obtaining an irredundant lattice PWA expression is also given.

In a worked example, the irredundant lattice PWA representation is used to express the explicit model predictive controller of a linear system, and the result turns out to be much more compact than that given by a state-of-the-art algorithm.

**Keywords:** continuous piecewise affine function, lattice piecewise affine representation, explicit model predictive control.

## 17:40 – 18:00, 14th, July

**The Impact of Process Variability on Statistical Process Monitoring**

*Geert Gins, Jef Vanlaer, Jan Van Impe, Department of Chemical Engineering, KU Leuven*

Process simulators are widely used to develop and benchmark techniques for Statistical Process Monitoring (SPM). Typically, the simulators are deterministic and do not take process variability into account. However, modern processes in (bio)chemical industry focus on bio-based production with the help of microorganisms, and are, therefore, subject to larger inherent process variability.

In this work, the influence of process variability on the performance of SPM is demonstrated in two representative case studies by adding different levels of process variability to the well-known Pensim benchmark simulator. In the first case study, a significant improvement (i.e., decrease) of fault detection times is observed. It is hypothesized that process variability causes a persistent excitation of the process, resulting in better process monitoring. In the second case study, a slightly poorer prediction of the batch-end quality was observed for increasing biological variability.

Both case studies clearly illustrate that process variability has a profound influence on the performance of SPM techniques. When employing computer-generated data for development, testing or comparison of techniques, the use of a simulator that includes process variability is highly recommended.

# Session 3: Identification and Fault Detection

## 09:00 – 09:40, 15th, July

**Data-driven Fault Diagnosis and Fault-tolerant-control**
*Steven X. Ding, Automatic Control and Complex Systems (AKS), Universität Duisburg-Essen*

Linear control theory is a well-established model-based framework, in which rich methods and tools are available for designing automatic control systems. In recent years, a trend can be observed that some of these design methods have been so modified that they can be directly applied based on process data sets instead of a process model. In this presentation, a data-driven design framework for observer-based fault detection and fault-tolerant control is introduced. It consists of (i) control-theoretical essentials (ii) data-driven forms of kernel and image representations (iii) a fault-tolerant control concept and (iv) realization and optimization techniques and algorithms.

## 09:40 – 10:00, 15th, July

**Output-only Fault Detection in Structural Engineering based on Kernel PCA**
*Edwin Reynders, Structural Mechanics Division, KU Leuven*

Structural health monitoring relies on the repeated observation of damage-sensitive features such as natural frequencies. A major problem is that regular changes in temperature, operational loading, etc., also influence those features. These influences are in general nonlinear and they affect different features in a different way. An improved technique based on kernel principal component analysis has been developed for eliminating these influences. The technique is output-only, which implies that only the damage-sensitive features need to be measured, not the environmental parameters. A nonlinear output-only model is implicitly identified by fitting it to training data in undamaged condition. Afterwards, the structure is monitored by comparing the model predictions with the observed features. The technique is validated with natural frequency data from a three-span prestressed concrete bridge, which was progressively damaged at the end of a one-year monitoring period.

## 10:00 – 10:20, 15th, July

**New Black-box Modeling for Novelty Detection and Semi-Supervised Learning**
*Vilen Jumutc, Department of Electrical Engineering, KU Leuven*

For many decades the problem of estimating a support for an unknown high-dimensional distribution was of a great interest in such fields of Machine Learning as Novelty Detection, Manifold Regularization and Semi-Supervised Learning. The One-Class and Laplacian Support Vector Machines are widely acknowledged kernel-based techniques to address this problem. However with the latter approaches it is difficult to model a mixture of distributions. We address this issue by presenting a new class of bilinear formulations where a new coupling term between classes is introduced. We focus on the Least-Squares formulation of the latter models which can be effectively translated into efficiently solved linear system of equations. We present experimental validation which justifies the usefulness and practical importance of the proposed methods both in the semi-supervised classification and novelty detection settings.

## 10:40 – 11:20, 15th, July

**A New Method for Frequency Domain Causality Analysis**
*Hao Ye, Department of Automation, Tsinghua University*

Partial directed coherence (PDC) is an important method for causality analysis in frequency domain. We expect that the frequency domain methods can provide a more detailed explanation of causal influence over different frequencies, but PDC provides no quantitative information to quantify the causal strength and the interpretation of causality over a specific frequency is still unexplained. To

deal with these problems, a new frequency domain causality analysis method based on the statistical property of the renormalized PDC will be introduced in this talk.

### 11:20 – 11:40, 15th, July

**Data-Driven Robust Receding Horizon Fault Estimation**
*Yiming Wan, Michel Verhaegen, Tamas Keviczky*
*Delft Center for Systems and Control, Delft University of Technology*

This talk presents a data-driven receding horizon fault estimation method for unknown linear time invariant systems, with enhanced robustness to stochastic identification errors. State-of-the-art methods construct fault estimators with identified state-space models or Markov parameters, but they do not compensate for identification errors. Motivated by this issue, we first propose a receding horizon fault estimator parameterized by predictor Markov parameters. It gives (asymptotically) unbiased fault estimates as long as the subsystem from faults to outputs has no unstable transmission zeros. When the identified Markov parameters are used to construct the above fault estimator, identification errors appear as model uncertainty multiplied with unknown fault signals and online data. Then, a mixed $\mathcal{H}_2/\mathcal{H}_\infty$ problem is formulated for the offline robust design that regards online data as unknown. To exploit the available online data, an online $\mathcal{H}_2/\mathcal{H}_\infty$ problem is also formulated. It can further reduce estimation errors when the online data have large amplitudes, at the cost of heavier computational burden. Based on geometrical interpretation of the offline and online optimization problems, systematic methods are given to tune the user-defined parameters therein. Simulation examples illustrate the benefits of our proposed methods compared against a recently proposed method in literature.

### 11:40 – 12:00, 15th, July

**An Application of Kernel Spectral Clustering to Predictive Maintenance**
*Rocco Langone, Department of Electrical Engineering, KU Leuven*

In general, an accurate prediction of forthcoming faults in modern industrial machines plays a key role in reducing downtime, increasing the safety of plant operations, and minimizing manufacturing costs. In this work we use clustering on the sensor data collected from a packing machine to recognize beforehand when the machine is entering a faulty regime. In this way an early warning can be raised and optimal maintenance actions can be performed. In particular, a clustering model is trained off-line and then employed on-line via its out-of-sample extension property to detect the need of maintenance due to dirt accumulation in the sealing jaws.

## Session 4: Data-driven Modeling and Learning

### 14:00 – 14:40, 15th, July

**Learning Theory Approach to A Family of Regularized M-Estimators**
*Yunlong Feng, Department of Electrical Engineering, KU Leuven*

In this report, we investigate the classical regression problem and our purpose here is to approximate the conditional mean of an unknown probability distribution. Starting with a non-convex loss function introduced in an information-theoretical learning setup, we give a general learning theory analysis. We then show that our analysis can be extended to a family of regularized M-estimators. Roughly speaking, we present a new framework of deriving the generalization bounds for a family of convex or nonconvex learning schemes.

## 14:40 – 15:00, 15th, July

**The Hashing Trick and Other Related Methods for Speeding-up Machine Learning**
*Ricardo Nanculef, Universidad Tecnica Federico Santa Maria*

The Johnson-Lindenstrauss lemma (JML) states that every set of $n$ points in a Hilbert Space of any dimension can be mapped into a space of dimension only $\mathcal{O}(\epsilon^2 \log n)$ in such a way that all distances between the points are preserved up to a multiplicative factor $1 + \epsilon$. This fact is very interesting in the context of current machine learning applications that need to manipulate lots of high dimensional objects such as images and text. It suggests that there exist methods to alleviate the curse of dimensionality and has indeed inspired powerful methods for dimensionality reduction and approximate computations in learning algorithms.

Among these methods, we have the random projections approach (RP), which is a surprisingly simple implementation of the JML, and the closely related *hashing trick*, which has been successfully employed to speed up support vector machines and other kernel methods. It can be shown that RP and the hashing trick are also closely related to some data sketches, that is, randomized data structures designed to obtain compact representation of massive data streams which approximately preserve some desired statistical properties.

This presentation provides a short introduction to these methods, explaining how they relate each other and highlighting several relevant considerations for putting them to use in machine learning.

## 15:00 – 15:20, 15th, July

**Data-driven Soft Sensor Modeling**
*Chao Shang, Department of Automation, Tsinghua University*

In industrial processes, product quality is a central focus because of its close relationship to economic interests. Because measurements of some quality indices are unavailable or costly, the soft sensing technique has been extensively implemented in process control community in past two decades as a real-time and reliable source of product quality estimations. The most-used soft sensors are data-driven ones, which establish prediction models based on the massive data archived. A comprehensive review of present popular data-driven soft sensor models is presented. By analyzing characteristics of process data, we consider semi-supervised learning and dynamic feature extraction as two primary solutions to further improvement of accuracy and applicability of soft sensor models. Several recent progresses in these two directions are introduced and some future works are discussed.

## 15:20 – 15:40, 15th, July

**Support Vector Machine with Pinball-loss and its Algorithms**
*Xiaolin Huang, Department of Electrical Engineering, KU Leuven*

To pursue the insensitivity to noise and the stability to re-sampling, a new type of support vector machine (SVM) has been established via replacing the hinge loss in the classical SVM by the pinball loss and was hence called a pin-SVM. The classical SVM is to maximize the distance between two sets, while pin-SVM is related to quantile distance, which follows that the performance for noise can be improved. We also discuss the solving algorithms for pin-SVM. Specifically, the dual problem of pin-SVM is a quadratic programming problem with box constraints, for which the sequential minimal optimization technique is applicable. Meanwhile, the optimal solution with the respect to tau, which reflects the quantile value, is a piecewise linear path. Motivated by the piecewise linearity, a traversal algorithm is established as well. With the help of this algorithm, a suitable tau could be found. Good statistical properties of pin-SVM and the effective algorithms together make pin-SVM a promising tool in pattern recognition.

# Poster Session

**Elevator Scheduling for Emergency Evacuation**
*Jing Wang, Department of Automation, Tsinghua University*

Traditionally, elevators are prohibited during many emergency cases, e.g., fire. With the recent development on fire prevention and reliable power supply system, some manufacturers consider elevator system for emergency evacuation because of its high speed. The goal of emergency evacuation by elevator is to disperse crowded population to safe places as quickly as possible, which naturally involves an elevator scheduling problem, called Elevator Scheduling for Emergency Evacuation (ESEE). ESEE is a special scheduling problem with a definitive destination. In this paper it is formulated as a mixed integer linear programming and proved to be equal to a split delivery vehicle routing problem (SDVRP). The equivalence means that ESEE is NP-hard and methods designed for SDVRP are applicable. Drawing lessons from SDVRP, this paper develops two algorithms for ESEE. Their performance in numerical experiments implies the potential use in emergency evacuation system.

**Holistic Controller Design: Safer and More Profitable Plants**
*Yuri A.W. Shardt, Steven X. Ding*
*Automatic Control and Complex Systems (AKS), Universität Duisburg-Essen*

With the increased emphasis on safety and environmentally friendly technologies, there is a growing need to extend the application of control. Not only must a control strategy be able to stabilise and maintain a process at its desired values, but it should also be able to assess control performance, detect process faults, diagnose and isolate the root causes, implement appropriate controller design changes, and perform lifetime maintenance. In order to accomplish this goal, there is a need to integrate the different aspects of the control strategy into a single comprehensive framework. The main areas of research include dealing with historical data, data mining, and soft sensor creation. The incorporation of this information into a single framework will allow for better and more efficient plants that can react to or even anticipate process changes.

**Tensor-based Algorithms for the Analysis of Data Similarity in a Blind System Identification Context.**
*Frederik Van Eeghem, KU Leuven*

Tensors are higher-order generalizations of vectors and matrices that have favorable properties for signal separation and similarity. In this work, a complete tensor-based framework has been developed for blind system identification (BSI). This framework contains both existing and new methods, and uses coupled decompositions in order to obtain more accurate system estimates. Also, the uniqueness of the resulting tensor decompositions is investigated. Using this BSI framework, tensor-based algorithms for system similarity were developed as well. When it suffices to know whether systems are equal or not, these algorithms are faster and lead to well conditioned results.

**Iterative Optimization of Process Monitoring and Fault Detection for Industrial Processes**
*Linlin Li, Automatic Control and Complex Systems (AKS), Universität Duisburg-Essen*

This presentation will provide a solution for real-time and iterative optimization of process monitoring and fault detection for industrial automation applications. To this end, minimum variance estimation in terms of recursive least square (RLS) or Kalman filter by iterative interactions with the process environment is addressed first to generate residual signals with a minimum variance. The optimal fault detection is then realized to provide the timely and optimal detection of potential problems by adopting these real-time minimum variance estimation schemes. For experimental tests, the iterative optimization of RLS estimation and Kalman filter, and their applications to fault detection are illustrated by a numerical example and a laboratory three-tank system study, respectively.