**Slovak University of Technology in Bratislava**
**Faculty of Chemical and Food Technology**
**Institute of Information Engineering, Automation, and Mathematics**

# Summaries Volume

## 21st International Conference on Process Control

**June 6–9, 2017, Štrbské Pleso, Slovakia**

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***The aim of the conference*** *is to exchange the recent advances and experience in the various areas of control theory between the researchers from industry, research institutes, project organisations, academies of sciences, and universities.*

***The program of the conference will be focused on*** *all aspects of control and systems, and ranges from fundamental research to applications in process control. Topics of interest include linear and non-linear control, optimisation, robust, adaptive and intelligent control, identification, modelling and simulations, real-time systems, new trends in application of industrial computer control, and education of qualified experts.*

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# Program

## Tuesday

**18:00–21:00 Dinner**

## Wednesday

**08:15–08:30 Opening**

**08:30–09:20 Pl-We-1 – Hall A – Plenary lecture**
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Chairman: Mercorelli, P.; Ilka, A.



**10:50 Coffee break**



**13:30–14:00 Lunch**

**14:00–18:00 Wo-We-4 – Hall A – Workshop: MPC**



**14:00–16:00 Le-We-5 – Hall B – Lectures: Tutorials, Benchmarks, and Surveys in Control (Invited Session)**
Chairman: Hurák, Z.

# Thursday

**08:30–09:20 Pl-Th-1 – Hall A – Plenary lecture**
Chairman: Kvasnica, M.



**09:30–12:30 Le-Th-2 – Hall A – Lectures: Model Predictive Control**
Chairman: Skogestad, S.; Belda, K.



**10:50 Coffee break**

# Friday

**09:30–10:50 Le-Fr-1 – Hall A – Lectures: Control Education**
Chairman: Kalúz, M.



**10:50 Coffee break**

**09:30–10:50 Le-Fr-2 – Hall B – Lectures: Modelling, Simulation, and Identification of Processes**
Chairman: Ogonowski, Z.



**10:50 Coffee break**

**11:10–12:30 Le-Fr-3 – Hall A – Lectures: Industrial Automation**
Chairman: Rosinová, D.

**11:10–12:30 Le-Fr-4 – Hall B – Lectures: Applications and Case Studies**
Chairman: Oravec, J.



**12:30–14:00 Lunch**

# Pl-We-1
# Plenary lecture

Chairman: *Fikar, M.*

08:30: **Economic Plantwide Control: Control Structure Design for Complete Processing Plants**

*Skogestad, S.*
Norwegian University of Science and Technology

A chemical plant may have thousands of measurements and control loops. By the term plantwide control it is not meant the tuning and behavior of each of these loops, but rather the control philosophy of the overall plant with emphasis on the structural decisions. In practice, the control system is usually divided into several layers, separated by time scale: scheduling (weeks) , site-wide optimization (day), local optimization (hour), supervisory and economic control (minutes) and regulatory control (seconds). Such a hierchical (cascade) decomposition with layers operating on different time scale is used in the control of all real (complex) systems including biological systems and airplanes, so the issues in this section are not limited to process control. In the talk the most important issues are discussed, especially related to the choice of "self-optimizing" variables that provide the link the control layers. Examples are given for optimal operation of a runner and distillation columns.

# Le-We-2
# Lectures: Linear and Non-linear Control System Design

Chairman: *Schlegel, M.; Hengster-Movric, K.*

09:30: **Generalized Output Synchronization of Heterogeneous Linear Multi-agent Systems**

*Hengster Movric, K., Šebek, M.*
Czech Technical University in Prague

This paper investigates output synchronization of heterogeneous linear time-invariant systems. Agents distributively communicate measured outputs and synchronize on regulated outputs. Necessary structure of single-agents' drift dynamics is used. Relations between single-agent dynamics, measured outputs and regulated outputs are investigated. Cooperative stability conditions reduce to requirements depending separately on single-agents' structure and interconnecting graph topology, allowing for a distributed control design. Sufficient condition is given based on coordinate transformations which reveal the effects of distributed control on single-agents. It is shown that identical subsystem state synchronization and robustness to interconnections guarantee regulated output synchronization.

09:50: **A Robustness Study of Process Control Loops Designed Using Exact Linearization**

*Wang, N., Kiss, B.*
Budapest University of Technology and Economics

Exact linearization is often applied to control nonlinear processes. This method requires not only the knowledge of the model structure but also the accurate parameter values. If the real parameter values of the controlled process are different from the nominal values used for the

exact linearization, the resulting system may not be linear or may have different gains and time constants as expected. A simple procedure is suggested that allows first the parameter grid based characterisation of the composition of the uncertain nonlinear system and its linearizing feedback for the nominal parameters and then the design of a $H_\infty$ controller. The approach is illustrated by simple examples including 1st order systems and the nonlinear Van der Pol oscillator.

10:10: **On Anisotropy-Based Control Problem with Regional Pole Assignment for Descriptor Systems**

*Belov, A.*[1] *, Andrianova, O.*[2]
[1] ITMO University
[2] Institute of Control Sciences, Moscow

In this paper, anisotropy-based control problem with regional pole assignment for descriptor systems is investigated. The purpose is to find a state-feedback control law, which guarantees desirable disturbance attenuation level from stochastic input with unknown covariance to controllable output of the closed-loop system, and ensures, that all finite eigenvalues of the closed-loop system belong to the given region inside the unit disk. The proposed control design procedure is based on solving convex optimization problem with strict constraints. The numerical effectiveness is illustrated by numerical example.

10:30: **IAE Based Tuning of Anti-windup Controller Schemes for First Order plus Dead-time System**

*Bušek, J., Vyhlídal, T., Zítek, P.*
Czech Technical University in Prague

The paper is focused on IAE based tuning the anti-windup feedback in a controller of a first order plus dead time model. The problem is addressed to two types of controllers, finite order PI and infinite order Internal Model Controller (IMC) with the delay compensation. For the PI a classical finite order feedback known as back-calculation method is utilized, whereas for the IMC, a novel functional feedback is proposed. For both the cases, the feedback setting is optimized with respect to minimizing the IAE criterion. The analysis is performed on a dimensionless form of the model so that the results are valid to a broad class of systems. For both PI and IMC, the 'optimal' dynamics of the anti-windup loop is of first order with the time constant being close to the time constant of the plant model.

11:10: **Control of a Two-Thermoelectric-Cooler System for Ice-Clamping Application Using Lyapunov Based Approach**

*Mironova, A., Mercorelli, P., Zedler, A.*
Leuphana University of Lueneburg

Homogeneous cooling of a metallic plate with the help of thermoelectric elements is crucial in terms of using it as a clamping device. By applying water on a plate and chilling it under subzero temperatures the resulting ice structure is able to fix workpieces form-fitted, ensuring proper holding and clamping forces for upcoming machining operations. For this purpose a number of thermoelectric coolers (TECs) need to be controlled such that a homogeneous temperature profile on the clamping plate is guaranteed as well as the prevention of thawing, especially if

external thermal disturbances occur due to machining processes like drilling, turning or milling. To face these challenges a robust controller is designed based on the Lyapunov Theory, proving its asymptomatic stability by means of two sliding surfaces. A clamping system consisting of two TECs, an aluminium clamping plate and a heat sink with forced convection is chosen for simulation purposes. This paper shows the model of such a system with corresponding controller design as well as the simulation results of the control strategy.

11:30: **Input Shaping Soutions for Drones with Suspended Load: First Results**
*Homolka, P., Hromčík, M., Vyhlídal, T.*
Czech Technical University in Prague

In this paper our first achievements are reported on application of input command shapers for control of quadcopters with suspended load. Simulation results are presented for a free 2DoF quadcopter. The flight control system, consisting of two PID controllers and of a static nonlinearity mapping the propellers thrusts to particular degrees of freedom, is augmented by input shapers in the feedforward path. Properties of the resulting control law are presented and further research proposals are elaborated.

11:50: **Digital Control of Ball & Plate Model Using LQ Controller**
*Spaček, L'., Bobál, V., Vojtěšek, J.*
Tomas Bata University in Zlín

This paper proposes the design of linear quadratic (LQ) digital controller in Ball & Plate model in experimental environment. The non-linear mathematical model of Ball & Plate structure is presented and adequately linearized. Polynomial approach to controller design for two degrees of freedom (2DOF) controller structure is introduced as the main tool for determination of unknown parameters. This method requires placing poles of characteristic polynomial, which are semi-optimally determined using minimization of linear quadratic criterion. This criterion is minimized by spectral factorization with the aid of the Polynomial Toolbox for MATLAB. Experiments have proved that this type of controller is able to stabilize the ball in desired position on the plate, reject external disturbances and follow reference path without much effort. In addition, a simple maze was created on the plate to extend possibilities of the choice of reference signal. The algorithm is able to determine correct path through the maze and navigate the ball along this path.

12:10: **Identification of n-link Inverted Pendulum on a Cart**
*Königsmarková, J., Schlegel, M.*
University of West Bohemia in Pilsen

The identification procedure specially designed for an n-link inverted pendulum on a cart is presented. By the Lagrangian mechanics, the mathematical model of the n-link inverted pendulum is established initially. To fully model the system, the standard dynamic parameters which are some algebraic functions of geometric, inertial, and friction parameters are introduced. Because the dynamic model of the n-link inverted pendulum is linear with respect to these parameters, the ordinary and weighted least squares techniques can be applied to estimation their values and the corresponding standard deviations. Also, the exact algorithms for numerical differentiation used in the formation of the regression model are described in detail. Finally, the results from

identification of the real triple inverted pendulum are presented.

# Le-We-3
# Lectures: Robust and Adaptive Control

Chairman: *Mercorelli, P.; Ilka, A.*

09:30: **Robust Nonlinear Model Predictive Control with Reduction of Uncertainty via Dual Control**

*Thangavel, S.*[1] *, Lucia, S.*[2] *, Paulen, R.*[3] *, Engell, S.*[1]
[1] TU Dortmund
[2] Otto-von-Guericke-Universität Magdeburg
[3] Slovak University of Technology in Bratislava

Dual control is a technique that solves the trade-off between using the input signal for the excitation of the system excitation signal (probing actions) and controlling it, which results in a better estimation of the unknown parameters and therefore in a better (tracking or economic) performance. In this paper we present a dual control approach for multi-stage robust NMPC where the uncertainty is represented as a tree of possible realizations. The proposed approach achieves implicit dual control actions by considering the future reduction of the ranges of the uncertainties due to control actions and measurements. The region of the uncertainties is described by the covariance of the parameter estimates. The proposed scheme does not require a priori knowledge on the relative importance of the probing action compared to the optimal operation of the system, as employed in other approaches. Simulation results obtained for a semi-batch reactor case study show the advantages of dual NMPC over robust (multi-stage) NMPC and adaptive robust NMPC, where the scenario tree is updated whenever a new measurement information is available.

09:50: **Robust Discrete-Time Gain-Scheduled Guaranteed Cost PSD Controller Design**

*Ilka, A., Mckelvey, T.*
Chalmers University of Technology

The most widely used controllers in industry are still the proportional, integral, and derivative (PID) and discrete-time proportional, summation, and difference (PSD) controllers, thanks to their simplicity and performance characteristics. However, with these conventional fixed gain controllers we could have difficulties to handle nonlinear or time-variant characteristics. The introduction of linear parameter-varying (LPV) systems led to various gain-scheduled controller design techniques in both state-space and frequency domain during the last 30 years. In spite of all these, there is still a lack of general approaches for advanced guaranteed cost PID/PSD controller design approaches for LPV systems. In this paper a new advanced controller design approach for discrete-time gain-scheduled guaranteed cost PSD controller design with input saturation and anti-windup is presented for uncertain LPV systems. In addition, the controller design problem is formulated in such a way, which gives convex dependency regarding the scheduled parameters. It results in a less conservative controller design compared to approaches using quadratic stability or the multiconvexity lemma and it's relaxations. Finally, a numerical example shows the benefits of the proposed approach.

10:10: **Robust Control for a Discrete-Time Uncertain System - Novel LMI Based Approach**
*Rosinová, D., Balko, P.*
Slovak University of Technology in Bratislava

In the paper, a novel robust controller design method is developed for discrete-time parameter varying system using matrix inequalities. Auxiliary matrices are used to reduce conservatism of the proposed robust stability conditions. The resulting design method is illustrated on examples.

10:30: **Robust Controller Design for Nonlinear Lipschitz Systems: Gain Scheduling Approach**
*Veselý, V., Körösi, L.*
Slovak University of Technology in Bratislava

The Paper is devoted to design of robust PID controller to the case of nonlinear Lipschitz systems using gain scheduling plant model approach. The proposed method is based on uncertain gain scheduled plant model, H2 performance (guaranteed cost) and Bellman Lyapunov equation.

11:10: **Robust Pitch Attitude Hold with MRAC for a Nonlinear Light Combat Aircraft Model**
*Wagner, D., Hromčík, M.*
Czech Technical University in Prague

In this paper, we implement a robust model reference adaptive control (MRAC) as part of an ongoing effort to demonstrate practical application of a nonlinear control system to the pitch - attitude hold of an aircraft model. We show that MRAC can improve transient performance and compensate changes in the performance characteristics of the aircraft mid-flight by evaluating an example where a change in center of gravity of the aircraft is coupled with decreased control effectiveness.

11:30: **Gaussian Trajectories in Motion Control for Camless Engines**
*Haus, B.*[1] *, Mercorelli, P.*[1] *, Werner, N.*[2]
[1] Leuphana University of Lueneburg
[2] Flensburg University of Applied Sciences

In the last few years, variable engine valve control has attracted a lot of attention because of its ability to reduce pumping losses and increase torque performance over a wider speed and load range. Variable valve timing also allows control of internal exhaust gas recirculation, thus improving fuel economy and reducing NOx emissions. One of the most important issues in this context is to track suitable variable (optimized in terms of engine speed and load) motion profiles for the intake and exhaust valves. This can be achieved using dedicated actuators for the valves instead of a traditional camshaft. This contribution considers a new kind of actuator for this purpose and its control for motion tracking in the context of camless systems. However, this paper's main intention is to introduce a method of generating variable engine valve trajectories that are based on Gaussian curves and exemplarily provide the reader with information on how to exploit their favorable mathematical properties for control design purposes. As a demonstration of this kind of curve's variability, a delay-compensating phase-adaptive feedforward action is derived from a linear model description of the actuator. Simulations show the effectiveness of

a simple heuristic delay-estimation algorithm in combination with the mentioned feedforward action.

11:50: **Robust Point-to-Point Control with Velocity Limitation**
*Kardoš, J.*
Slovak University of Technology in Bratislava

In the contribution, an original modification of the special kind of robust point-to-point (fixed target) motion control with the intentional limitation of maximal velocity is presented. Theoretical background of the provided control algorithm is given by the variable structure control theory yielding the fast and accurate time sub-optimal control. This ensures the desired quality and integrity of the motion control despite the presence of significant parametric and signal disturbances. Simulation results show the reliability of the presented control method.

12:10: **Robust LPV-based Infinite Horizon LQR Design**
*Ilka, A.*[1] *, Veselý, V.*[2]
[1] Chalmers University of Technology
[2] Slovak University of Technology in Bratislava

In this paper, the problem of robust infinite horizon linear quadratic regulator (LQR) design is addressed for uncertain affine linear parameter-varying (LPV) systems. The proposed method extends the standard infinite horizon LQR design to LPV-based static output-feedback (SOF), dynamic output-feedback (DOF) and to a well known proportional, integral and derivative (PID) controller design for uncertain affine LPV systems. The optimal (suboptimal) controller design is formulated as an optimization problem subject to some linear/bilinear matrix inequality (LMI/BMI) constraints. As the main result, the suggested performance and stability conditions, without any restriction on the controller and system structure, are convex functions of the scheduling and uncertainty parameters. Hence, there is no need for applying multi-convexity or other relaxation techniques and consequently the proposed solution delivers a less conservative design method. The viability of the novel design technique is demonstrated and evaluated through numerical examples.

# Wo-We-4
# Workshop: MPC

14:00: **Distributed Optimization and Control with ALADIN**
*Houska, B.*
ShanghaiTech University

This workshop consists of two interactive tutorial presentations. The first presentation gives an overview about distributed convex and nonconvex optimization algorithms of recent interest such as dual decomposition, the alternating direction method of multipliers (ADMM), and the augmented Lagrangian based alternating direction inexact Newton method (ALADIN). We discuss how these methods perform for different types of problems and share experience on which algorithms and settings are suited for which types of optimization problems.
The second presentation focuses on applications of ALADIN with a particular focus on large-

scale applications in model- based process control. In particular we discuss how to detect and exploit structure in different types of control applications ranging from distributed traffic control at intersections, nominal and stochastic optimization of AC power flows in large electrical networks, to plant-wide chemical process optimization and control.

# Le-We-5
# Lectures: Tutorials, Benchmarks, and Surveys in Control (Invited Session)

Chairman: *Hurák, Z.*

14:00: **Inverse Feedback Signal Shapers: State-of-the-art, Applications, Perspectives**
*Hromčík, M., Vyhlídal, T.*
Czech Technical University in Prague

The talk is meant as a summary presentation reated to our continuing research on inverse feedback input shapers. We shall present the main idea and elaborate it into a computationally tractable and practically implementable scheme using the theory of input shapers with distributed delays. Applications for classical problems of crane control or flexible servomechanisms shall be demonstrated and recent results for less traditional setups - e.g. helicopters or drones with suspended load - will be introduced.

14:20: **Ball in Hoop Revisited as Laboratory Benchmark for Advanced Control**
*Gurtner, M., Zemánek, J., Hurák, Z.*
Czech Technical University in Prague

In this talk, we revisit Ball and hoop system, a well-established laboratory model used in education of linear control systems, and show that it is also suitable for demonstration of more advanced control techniques. In contrast to the standard use, we describe the dynamics of the system at full length by a hybrid model; in addition to the mode where the ball rolls on the (outer) hoop we also consider the mode where the ball drops out of the hoop and enters a free-fall mode. Furthermore, we add another (inner) hoop in the center upon which the ball can land from the free-fall mode. This hybrid description of the Ball and hoop system enables us to generate dynamically rich trajectories (for instance, the ball can go through the top of the hoop or even fly in free fall) and pose challenging control task. We present two such tasks and show how they can be solved by trajectory generation and stabilization. We also describe how such a laboratory model can be built and we experimentally verify the validity of our approach to solution of the proposed tasks.

14:40: **Overview of Research in Non-contact Manipulation Using Dielectrophoresis at CTU in Prague**
*Michálek, T., Gurtner, M., Zemánek, J., Hurák, Z.*
Czech Technical University in Prague

The aim of this talk is to give an overview of the research conducted by our group over the last couple of years in the field of non-contact micromanipulation. In this research, we exploit the phenomenon of dielectrophoresis as a means of exerting a force on a microscale object by shaping an external electric field. The ultimate motivation for our research comes from the domain of bion-

analytical instrumentation because this technology allows biological cells to be the manipulated objects. The focus of the talk will be on modeling, estimation, and control design. After introducing the very basic principle of dielectrophoresis including a description of a control-oriented mathematical model, the key idea behind the hierarchical control strategy will be explained - the higher-level positioning controller determines a required force that needs to be created at a given spot(s) and then the voltages that are to be applied to an array of microelectrodes are computed by solving a numerical optimization. The key computational challenge comes from the need to solve a nontrivial optimization in real time. Our description will be supported by data obtained using an experimental setup which uses our own simple yet clever layout of the microelectrodes enabling to perform a full three-dimensional manipulation of one or several microobjects. Another distinguished feature of our setup is that full 3D position of the manipulated object can be estimated in real-time using lensless visual sensing. Videos from experiments demonstrating a successful manipulation of one or several microobjects will also be presented.

15:00: **Slotcars for Vehicular Platooning**
*Hurák, Z.*
Czech Technical University in Prague

We describe a mature project aiming at development of an affordable experimental platform for research in vehicular platooning. It consists of several autonomously controlled slotcars. We equipped each off-the-shelf slotcar with an onboard computer (the popular Raspberry Pi Compute Module) as well as with numerous sensors that make the car capable of measuring its own velocity, acceleration, and distances to its nearest neighbors (both ahead and behind). Onboard wireless communication interface (wifi) allows to include in the control computations also the states and controls of other vehicles, in particular the leader of the platoon. All data are wirelessly transferred to an operator PC for convenient visualization and offline analysis (in Matlab, for example). The platform currently serves to demonstrate various platoon control strategies, such as predecessor following, (a)symmetric bidirectional control or cooperative adaptive cruise control (CACC). The experiments with the platform demonstrate all the known effects of the platoon dynamics such as string instability. In fact, thanks to fast dynamics of the slotcars, these effects are even more pronounced than with real-size vehicles, hence the platform constitutes a challenging experimental benchmark for theoretical research in vehicular platooning. Indeed, the primary motivation behind this development was to offer to the control systems community an affordable yet physically relevant and realistic means to verify and demonstrate theoretical findings in vehicular platooning with experimental data. Thus all the source code, schematics and component lists are made publicly available. More information is at the project's webpage on hackaday.io web page https://hackaday.io/project/19087-slotcars-for-vehicular-platooning.

15:20: **Traveling Wave and Scattering Approaches to Control of Chains**
*Hurák, Z.*
Czech Technical University in Prague

In this talk we introduce a powerful and convenient framework for modeling, analysis and control synthesis of interconnected lumped (physical) dynamical systems. Although we restrict ourselves to a chain type of an interconnection, the framework can extend to general interconnection topologies. The motivation for this research comes from the physical domains as diverse as robotics,

electronics, hydraulics, and even vehicular platooning. We borrow from the well developed areas of distributed parameter systems such as transmission lines, flexible mechanical structures and (thermo)acoustic systems and show that numerous phenomena in chains of lumped systems can be modeled by superposition of incident and reflected traveling waves. The goal of control design can then be formulated as finding the matching impedance. We will carefully discuss various concepts of impedance matching. We will also show how the scattering description well mastered by electrical engineers allows us to to transition from physical variables to wave variables. This, in turn, prepares the ground for the popular H-infinity optimal control framework. Although all the above mentioned concepts are classical, it may be useful to see them formulated in the language of control theory and it may come as a surprise to see that they can be applied in control application domains such as vehicular platooning. In the talk we also compare these results with the relatively new framework based on the so-called wave transfer functions as invented and promoted by W. O'Connor in the field of flexible robotic manipulators. In fact, we will show that these are equivalent.

15:40: **Experimental Modular Platform for Distributed Planar Manipulation by Magnetic Field**

*Zemánek, J., Hurák, Z.*
Czech Technical University in Prague

This talk presents an experimental platform for testing of control algorithms for distributed manipulation. The system dubbed MagMan (Magnetic Manipulator) consists of a rectangular array of coils, above which steel balls are rolling. The system measures the position of balls using a resistive touch foil or a camera and controls individual coils accordingly. A simplified mathematical model of the system describes both the magnetic force and the ball's dynamics. To find the parameters of the model, we used measurements of the magnetic field, exerted force, and velocity profiles. Besides the experimental system, we also present an example of the control algorithm based on feedback linearization; it attempts to invert the mathematical model using a numerical optimization that finds the currents for demanded force. Finally, we present results and videos from experiments and we discuss possible further extensions of the system. The platform may be attractive especially for groups studying control algorithms for nonlinear systems and distributed systems.

# Po-We-6
# Poster Session

Poster: 1

**A Web-based Tool for Design of Simulink Models**

*Čirka, Ľ., Kalúz, M.*
Slovak University of Technology in Bratislava

This paper deals with the development of an educational web-based application that allows users to create simple block schemes in the Internet browser. The structure of created schemes is based on XML, and it is entirely compatible with the Simulink environment. The application allows the user to perform an evaluation of created schemes by executing them in the remote instance of

MATLAB/Simulink via an HTTP MATLAB Web Server. The result of the simulation is returned either in the form of a graph or a data file for further processing. The application can be used in education for a teaching of systems' modeling and control, and also as a support tool for development of virtual and remote laboratories.

Poster: 2
**The Concept of Virtual Laboratory and PIL Modeling with REX Control System**
*Ozana, S., Docekal, T.*
VŠB - Technical University of Ostrava

This paper deals with the description of concept of a virtual laboratory designed for educational purposes and deployment of processor-in-the-loop (PIL) concept with the use of the REX Control System. It also presents the case study regarding control of a simple inverted pendulum on the cart. The below mentioned techniques represent modern, accessible and adaptive teaching methods supporting a distance education.

Poster: 3
**Computer Game as a Tool for Machine Learning Education**
*Doležel, P., Dvorak, M.*
University of Pardubice

The effective education is one of very important and everlasting challenges of human society. With each generation of students, new approaches have to be implemented to keep the process of education prosperous. This paper introduces a small piece to a set of modern tools for education of Informatics and Electrical Engineering. To be more specific, an interactive software for machine learning testing and demonstration is presented in this paper. The software is designed especially to be used as a motivation and a first encounter to these areas of technical studies, while it supports individual efforts of the students. In the paper, the software architecture is described and, in the second half of the paper, some possibilities of software usage in education process are suggested.

Poster: 4
**Tuning Rule for Linear Control of Nonlinear Reactive Sputter Processes**
*Wölfel, C.T., Awakowicz, P., Lunze, J.*
Ruhr-Universität Bochum

A tuning rule for the linear control of nonlinear reactive sputter processes is developed based on a process model, which has the form of an Abel differential equation. The process characteristics relates to a supercritical Pitchfork bifurcation with stable and unstable equilibrium states. The paper presents a tuning rule to achieve a desired closed-loop transition behavior and set-point following for step-shaped reference signals without the need of an identified process model. The tuning rule is deduced from the given stability conditions. Experiments are presented for the validation of the developed control structure and the proposed tuning rule. They show that reactive sputter processes can be systematically tuned to achieve a desired closed-loop behavior.

Poster: 5
**Compromising Controller Parameters Setting for a Delayed Thermal Process**
*Pekař, L., Prokop, R.*
Tomas Bata University in Zlín

The primary goal of this contribution is to present an original idea of a suboptimal controller parameters setting that intends to achieve a compromise between various requirements on the control response performance. Performance (quality) measures include integral and absolute criteria. The idea is demonstrated and applied to a robust control of a thermal process that shows internal delays. As the subsidiary objective, the reader is acquainted with a concise summary of the robust control design for the delayed model based on the algebraic principle over a special ring. The obtained results are demonstrated not only by means of computer simulations but via laboratory measurements as well.

Poster: 6
**Fuzzy Control of a Laboratory Binary Distillation Column**
*Drgoňa, J., Takáč, Z., Horňák, M., Valo, R., Kvasnica, M.*
Slovak University of Technology in Bratislava

This paper deals with control of a laboratory binary distillation column used for separation of methanol from water. The focus of this paper is the tutorial demonstration of the model-free fuzzy control design for the laboratory device. The performance and the control synthesis of the fuzzy control approach are moreover compared with classical PID controller.

Poster: 7
**Power Plant Steam Superheater Control System: Preliminary Results and Experiences from the Field Tests**
*Hubka, L., Školník, P., Hlava, J.*
Technical University of Liberec

This paper describes a newly developed steam superheater control system and its integration into the real power plant control system. The developed control system is based on the principles of the model predictive control. It is intended to replace one part of the existing classical control system that is based on gain scheduled PID controllers. The paper starts with a short description of the controlled plant and then it continues with the description of the predictive controller and its integration into the structure of the existing control system. The main focus is on the results of the functionality tests. The preliminary results hitherto achieved demonstrate the capability of the developed control system and its application potential. However, at the same time, they also show that extensive simulation testing of a controller for such a complex system does not necessarily guarantee perfect control performance and several modifications of the controller will be needed to make it really applicable.

Poster: 8
**Probabilistic Advisory System for Operators Can Help with Diagnostics of Rolling Mills**
*Puchr, I., Herout, P.*
University of West Bohemia in Pilsen

Advisory system for operators of complex industrial processes has been developed and improved by a international team of scientists and people from industry since 2000. Main purpose of the advisory system is to help operator set up manually adjustable parameters of an industrial process, with the aim to reach required production quality. Industrial process is taken for a stochastic process and input signals of its control system are taken for random variables. Based on Bayesian probability theory, a software toolbox was created for handling mixtures of probability density functions describing behavior of the process. Advisory system was tested and pilot application was installed on rolling mills producing metal strips. During the tests, an idea emerged to exploit verified probabilistic approach for complicated diagnostic tasks too. This diagnostics is intended for recognition of process malfunction which cannot be easily revealed by analysis of particular single signals only but analysis in multidimensional data space must be involved instead. Main principle of the advanced diagnostic method consists in finding a representation of process behavior in a short history by a mixture of probability density functions called historical mixture. Process behavior in the latest time period is represented by actual mixture. Difference between historical and actual mixtures is evaluated by calculation of Kullback-Leibler divergence. Mixtures and divergences are calculated repeatedly in time and a big change in the divergence value can be used as a source of alarm for non-standard process behavior.

Poster: 9
**Analysis of the Hydrometeorological Data Using the Fractal Dimension Estimation**
*Jura, J., Novak, M.*
Czech Technical University in Prague

This paper deals with an evaluation of a hydrometeorology data from sites of a different land use and mainly from the places with a different leaf area index. Two methods of an estimation of the Fractal Dimension of a hydrometeorology time series, which is based on the original principle of coastline length measuring, were developed. Also indicator of autoregulation of temperature in the ecosystem was prosed. The first results indicate that developed methods are usable for testing of the relation between measured data and autoregulation functions of the ecosystem.

Poster: 10
**Development of Inferential Models for Fractionation Reformate Unit**
*Ujević Andrijić, Ž., Mohler, I., Bolf, N., Dorić, H.*
University of Zagreb

Industrial facilities show an increasing need for continuous measurements and monitoring a large number of process variables and properties due to strict product quality requirements, environmental laws and advanced process control. On-line analyzers often suffer from long measurement delay which is not desirable for closed-loop implementation. Laboratory assays are irregular and not suitable for process control. Inevitable alternative are soft sensors and inferential control. Since production standards in refineries become more stringent, there is a need for continuous

monitoring and control of benzene content in gasoline. Development of soft sensor models for the estimation of light reformate benzene content is carried out. Linear dynamical autoregressive model with external inputs (ARX), autoregressive moving average model with exogenous inputs (ARMAX) and Box-Jenkins (BJ) models are developed. For the problem of regression vector optimization usually performed by trial and error, Genetic Algorithm (GA) and Simulated Annealing (SA) methods have been applied. The results indicate that the GA and SA as global optimization methods are both suitable for the regressor order estimation of linear dynamical models with multiple inputs. This makes the development of soft sensors easier and systematic. Based on developed soft sensors, it is possible to apply advanced process control for better product quality.

Poster: 11

**Model Predictive Control of a Combined Electrolyzer-Fuel Cell Educational Pilot Plant**

*Ingole, D., Drgoňa, J., Kalúz, M., Klaučo, M., Bakošová, M., Kvasnica, M.*
Slovak University of Technology in Bratislava

In today's era of renewable energy, hydrogen fueled proton exchange membrane (PEM) fuel cells are considered as an important source of clean energy. As the technology is emerging fast, many universities and colleges have adopted fuel cells in their educational program. In this paper, we will present the modeling and control of the fuel cell pilot plant present in Clean Energy Trainer, which is used by students and researchers in many universities. The plant under consideration is a laboratory-scale pilot plant designed mainly for verifying the applicability of theoretically studied control strategies on the real-world application. The plant is a series connection of electrolyzer and a PEM fuel cell stack with one input and one output. The control of such a plant is the challenging research problem due to the nonlinearities, slow dynamics, dynamics and physical constraints. The control oriented data-driven model of the plant is developed and validated through a series of experiments. To tackle the electrolyzer-fuel cell control problem, we present a model predictive control (MPC) scheme that can take into account the physical constraints of the plant. In addition to the controller, a disturbance observer is designed to cope with the external disturbances and to avoid adverse effects on the system performance. Subsequently, the developed control scheme is successfully implemented in real-time. Highly satisfactory results are obtained, regarding reference tracking, constraint handling, and disturbance rejection.

Poster: 12

**Enhancing Disturbance Rejection Performance for the Magnitude-optimum-tuned PI Controller**

*Cvejn, J.*
University of Pardubice

The Magnitude Optimum (MO) tuning method for PI and PID controllers, applied on stable and non-oscillating plants, usually gives fast tracking responses and offers very good process output disturbance-rejection performance, even if the process contains significant dead time. On the other hand, in the cases of plant-input disturbances slow responses may be obtained. The paper deals with this problem for the PI controller case. Enhancing the disturbance-rejection performance is achieved by means of additional filter designed so that the stability margin properties of the MO tuning are preserved.

Poster: 13
**Predictive Control of Nonlinear Plant Using Piecewise-Linear Neural Model**
*Honc, D., Doležel, P., Gago, L.*
University of Pardubice

A special form of a predictive controller is presented in this paper. Based on previous authors' work, a piecewise-linear neural model of nonlinear plant to be controlled is adopted to local linearization. The linearized model is then used for control action evaluation using a predictive controller. Although the linearization using piecewise-linear neural network is simple and efficient, it provides the model in a nonstandard form. Therefore, the proposed predictive controller is designed in order to handle that nonstandard model without any customization. An illustrative example demonstrates the main features of the introduced solution.

Poster: 14
**Learning Control of a Robot Manipulator Based on a Decentralized Position-dependent PID Controller**
*Cvejn, J., Tvrdík, J.*
University of Pardubice

The paper describes an approach to learning feedback control of a robot manipulator, based on partitioning of the joint space into segments. Within each segment the robot is controlled as a decoupled linear system by means of conventional PID controllers. To achieve continuity of control variables the segments are represented as fuzzy sets. The controller settings are adapted by online identification from past measurements of position and control signals.

Poster: 15
**Control of a Biochemical Process Using Fuzzy Approach**
*Vasičkaninová, A., Bakošová, M., Mészáros, A.*
Slovak University of Technology in Bratislava

The work deals with design and application of fuzzy controllers for a biochemical process. Fuzzy logic control based on the Takagi-Sugeno inference method has been applied for control of the baker's yeast fermentation. The advantage of the fuzzy control design is that it can be used very successfully for control of strongly non-linear processes and processes that are difficult to model because of complicated reaction kinetics. Obtained simulation results confirm this fact. The disadvantage of the fuzzy control design lies in the time-consuming tuning of controllers.

Poster: 16
**Internal Model Control of Thermo-Optical Plant**
*Paulusová, J., Paulus, M.*
Slovak University of Technology in Bratislava

In this paper a robust predictive neuro-fuzzy control method for a nonlinear plant is addressed, proposed and tested. A neuro-fuzzy model is used to identify the process and then provides predictions about the process behavior, based on control actions applied to the system. The paper consists of theoretical and practical section, offers an internal model control and a neuro-fuzzy internal model control designs and their successful application. The structure of both of algorithms

is described in detail. The proposed control algorithms are applied to control of a thermo-optical plant.

Poster: 17
**Optimal Operation of Nanofilter Based Diafiltration Processes Using Experimental Permeation Models**
*Sharma, A., Jelemenský, M., Paulen, R., Fikar, M.*
Slovak University of Technology in Bratislava

In this paper, a choice of models for optimal control strategy is discussed for batch membrane processes. The system of lactose and salt in water is studied with the separation aim be- ing concentration of lactose and simultaneous removal of salt. The most crucial part of the model is dependence of permeation rate on concentrations of components. Two models from literature and one data-based model are fitted to experimental data. An optimal control problem (OCP) is formulated to minimize processing time using diluant-to-permeate flow ratio as the control input. The optimal control strategy is found analytically and verified using numerical methods of dynamic optimization. The resulting processing times and the optimal input profiles are compared between all the models. Simulation case study confirms the attractiveness of the proposed approach.

Poster: 18
**A Novel Approach of Control Design of the pH in the Neutralization Reactor**
*Holaza, J., Valo, R., Klaučo, M.*
Slovak University of Technology in Bratislava

This paper deals the with design of a control strategy which will effectively control the level of pH in a neutralization reactor in the whole range of pH. The process consists of a continuously stirred tank, where aqueous solutions streams of acetic acid and of sodium hydroxide are mixed together. The main challenge of a successful control strategy for this process arises mainly from its nonlinear behavior. The paper will show how to handle such non-linearity efficiently by introducing an augmented output and an optimization based control. Simulation results will be given to demonstrate the behavior of the proposed control strategy. Comparison between an optimal based controller and a simple PI controller is discussed.

Poster: 19
**Comparitive Study of Predictive Controllers for Trajectory Tracking of Non-holonomic Mobile Robot**
*Sharma K., R., Dušek, F., Honc, D.*
University of Pardubice

The paper deals with predictive control of non-holonomic mobile robot. The basic nonlinear kinematic equation is linearized into two different linear time varying models based on frame of reference – world coordinates and local coordinate of mobile robot. The non-linear model predictive control is applied to the trajectory tracking problem of a non-holonomic mobile robot with these models. The control law is derived from a cost function which penalizes the state tracking error, control effort and terminal state deviation error. Various simulation experiments are

conducted and a comparative analysis has been made with respect to state-of-the-art approaches.

Poster: 20

**Navigation Control and Stability Investigation of a Hexacopter Equipped with an Aerial Manipulator**

*Ibrahim, I.*[1] *, Božek, P.*[2] *, Al Akkad, M.A.*[1] *, Almaghout, K.*[3]
[1] Kalashnikov Izhevsk State Technical University
[2] Slovak University of Technology in Bratislava
[3] University of Tehran

In this paper, the dynamics model of a hexacopter equipped with a robotic arm has been formulated using Newton-Euler's method and its stability was investigated. For disturbances emulation a simplified pendulum method was used. This Hexacopter configuration was not covered in scientific papers before. The resulting model is a nonlinear, coupled, and underactuated dynamics model, which includes aerodynamic effects and disturbances because of equipping the hexacopter with a robotic arm. The purpose of the presented paper is to offer a comprehensive study of determining the inertia moments of the hexacopter using a simplified pendulum method, taking into consideration the effect of mass distribution and center of gravity changes, which are a result of the continuous movement of the manipulator during the hexacopter motion in the air. The experimental tests were made using solid works application and were evaluated using LabVIEW in order to get a complete view of the disturbances, which were inserted into the dynamics model. The overall aircraft model was driven by four classical PID controllers for the vehicle's attitude and altitude of a desired trajectory in the space. These controllers were used to get a good understanding of how to evaluate and validate the model to make it an anti-disturbance model, in addition to their ease of design and fast response, but they require development in order to get optimal results. In future, a precise trajectory will be defined, and the controllers will be developed in order to get robust stability using nonlinear techniques and artificial intelligence.

Poster: 21

**The Initial Analysis of Failures Emerging in Production Process for Further Data Mining Analysis**

*Németh, M., Michal'čonok, G.*
Slovak University of Technology in Bratislava

The aim of this paper is to examine possibilities for the initial data analyses of the failure data from industrial production process. To perform the initial data analysis of the data from production process we have used graphical statistical method and also data mining methods like drill-down analysis and cluster analysis. Before applying mentioned techniques and methods it was necessary to know the principle of the industrial production process itself and also to be aware of the failure data structure. This initial data analysis is vital to be able to review the knowledge potential of given data. Based on this, we are able to point out interesting issues, that can be further solved with KDD (knowledge discovery from databases) techniques.

Poster: 22
**Modelling of Ball and Plate System Based on First Principle Model and Optimal Control**
*Dušek, F., Honc, D., Sharma K., R.*
University of Pardubice

This paper presents modelling of ball and plate systems based on first principles by considering balance of forces and torques. A non-linear model is derived considering the dynamics of motors, gears, ball and plate. The non-linear model is linearized near the operating region to obtain a standard state space model. This linear model is used for discrete LQ control of the ball and plate system – the trajectory of the ball is controlled by control voltages to the motor.

Poster: 23
**Finite Element Method Based Modeling of a Flexible Wing Structure**
*Svoboda, F., Hromčík, M.*
Czech Technical University in Prague

The finite element based structural model of a flexible wing is presented. The structural model will be a part of a servoelastic wing used for flutter analysis and designing flutter suppression control systems. It also allows modal analysis of a wing with given parameters. A finite element model consists of Euler-Bernoulli beams joined together. This approach is able to reach high accuracy and various properties of a particular wing element can be modeled.

Poster: 24
**Modelling of Hybrid CSTR Plant: Heat Transfer Considerations**
*Laszczyk, P., Niedzwiedz, M., Skupin, P., Metzger, M.*
Silesian University of Technology Gliwice

The continuously stirred tank reactor (CSTR) may exhibit various nonlinear effects, for example, multi-stability or sustained oscillations. This makes the CSTR one of the most difficult industrial units for control and the system instability or thermal runaway indicate that the safety issues must also be taken into account. In comparison to the real reactor, a hybrid system is safe and less expensive alternative for testing new concepts in control. In this paper, we consider a hybrid reactor that consist of a jacketed vessel and LabVIEW based real-time simulator of a chemical reaction. To make the hybrid reactor a highly nonlinear benchmark plant, the system parameters must be carefully selected. Instead of making time consuming experiments, the preliminary simulation tests would be helpful in selection of the process parameters. For this purpose three models of various complexity for the real hybrid reactor are developed. We show that an overall heat transfer coefficient cannot be assumed constant to obtain a good agreement between the simulation results and the measurement data. The paper also presents the influence of the coefficient on the dynamical behavior of the hybrid reactor based on the bifurcation analysis.

Poster: 25
**From Stochasticism to Determinism in Evaluation of Human Postural Responses**
*Barbolyas, B.*[1] *, Bzdúšková, D.*[2] *, Vachálek, J.*[1] *, Belavý, C.*[1] *, Dedík, L.*[1]
[1] Slovak University of Technology in Bratislava
[2] Slovak Academy of Sciences, Bratislava

The Center of Pressure (COP) signal is a kind of human postural response and it is an established indicator of human ability to maintain balanced posture. Its form of the statokinesigram has complicated profile, which suggests stochastic or chaotic nature of COP movement. Here is presented developed statokinesigram trajectory (DST) as a basis of method for human postural response analysis. Since DST does not show signs of stochastic behavior it is suitable for modeling with help of linear system theory. In this study, volunteer's postural responses were affected by bilateral vibration stimuli of Achilles tendons. This vibration stimulus causes nonlinear response in anterior-posterior direction. DST allows to analyze this phenomenon through mathematical model in form of a transfer function. Its estimated parameters are useful in evaluation of human posture control.

Poster: 26
**Linear Analysis of Lateral Vehicle Dynamics**
*Mondek, M., Hromčík, M.*
Czech Technical University in Prague

Systematic analysis of lateral dynamics of a ground vehicle (e.g. passenger car) is presented in this paper. The results are based on the simplest possible single-track model. Effects of variations in the physical parameters - mass, the moment of inertia, tire priorities, vehicle geometry - on the response times, damping ratios, natural frequencies and other dynamical characteristics are presented and confronted with intuitive and "common sense" expectations and with real-life experience of race car drivers and constructors. We believe that such a report is quite unique and useful by itself: we are not aware of any similar existing report which would provide this systems-and-controls viewpoint on the vehicle dynamics phenomena. In addition, future plans are to apply modern systematic model based control design approaches to come up with active dynamics modifications solutions - using for instance torque vectoring - surpassing current approaches based mainly on mechanical redesigns and, to some extent, simplest possible local feedback controllers.

Poster: 27
**Tram Simulation Model for Energy Balance Analyses**
*Hubka, L., Školník, P.*
Technical University of Liberec

This paper describes a mathematical model of a tramcar which allows to simulate traffic on any tram track and allows to analyze energetic balance on the electrical power link without real energetic data measurement. The described mathematical model could be a useful tool for the design of an energy recovery system for a real tram track. A short description of the tram track model in the city of Liberec is presented together with the mathematical model of the tramcar type T3.PLF that operates on mentioned track. The model simulation results are confronted with data measured

during the real tram operation.

Poster: 28
**Modeling of Magnetic Levitation System**
*Balko, P., Rosinová, D.*
Slovak University of Technology in Bratislava

The paper is devoted to modeling and parameter identification for Magnetic Levitation System (MLS) from Inteco. MLS belongs to challenging modelling and control problems due to its unstability and nonlinearity. We concern several modeling details not sufficiently described in user manual, a correction of nonlinear model, and present the corresponding measurement results. The obtained nonlinear model parameters and corresponding linearized model fits the real data much better than parameters provided in the reference.

Poster: 29
**The Digital Twin of an Industrial Production Line within the Industry 4.0 Concept**
*Vachálek, J.*[1] *, Bartalsky, L.*[1] *, Morháč, M.*[2] *, Lokšík, M.*[1] *, Rovný, O.*[1] *, Šišmišová, D.*[1]
[1] Slovak University of Technology in Bratislava
[2] SOVA Digital a.s.

This article presents the digital twin concept, which is an augmented manufacturing project created in close collaboration by SOVA Digital and the Institute of Automation, Measurement and Applied Informatics (ÚAMAI), of the Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava with the support of SIEMENS. The project is a technological concept focusing on the continuous optimization of production processes, proactive maintenance, and continuous processing of process data. This project is the basis for further work to promote the concept of Industry 4.0. for the needs of the industry subjects within Slovakia. Its basic goal is to support the existing production structures within the automotive industry and the most efficient use of resources by augmented production and planning strategies, such as the digital twin presented here.

Poster: 30
**PLC Control of Casting Mold Preheating Process as Distributed Parameter System**
*Bartalsky, L., Belavý, C., Bartko, M., Hulkó, G., Kubiš, M.*
Slovak University of Technology in Bratislava

In the paper a problem of casting die preheating control is solved. Concept of the control is designed based on distributed parameters systems. The design of the control structures are created within simulation studies, afterwards are connected into cosimulation regime network to tune the control parameters and then applied to control of preheating using PLC.

Poster: 31
**Distributed Adaptive Consensus Protocol with Laplacian Eigenvalues Estimation**
*Knotek, Š., Hengster Movric, K., Šebek, M.*
Czech Technical University in Prague

This paper addresses distributed consensus problem for multi-agent systems with general linear time-invariant dynamics and undirected connected communication graphs. A distributed adaptive consensus protocol is found to solve problems of existing adaptive consensus protocols related to different, generally large and possibly unbounded coupling gains. This protocol guarantees ultimate boundedness under all conditions, however for an asymptotic stability, a proper estimation of reference values for coupling gains is required. Here, we propose an algorithm for the estimation of the coupling gain reference. The algorithm is based on a distributed estimation of the Laplacian eigenvalues. In comparison to the previously proposed algorithm based on the interval halving method, this algorithm offers robustness to change of the network topology. In addition, it decouples the estimation from the consensus protocol, hence it does not influence stability properties of the adaptive consensus protocol.

Poster: 32
**Robust PID Controller Design for the Magnetic Levitation System: Frequency Domain Approach**
*Hypiusová, M., Kozáková, A.*
Slovak University of Technology in Bratislava

The paper deals with the frequency domain design of a robust PID controller for unstable SISO systems. The approach applied is based on performance specification in terms of phase and gain margins; to guarantee the desired performance a modification of the Neimark D-partition is used. In the practical application a PID controller has been designed for the laboratory Magnetic Levitation System.

Poster: 33
**Testing Device Design for Validation of Synchronization between High Speed Camera and Drop Weight Test Machine**
*Pospisilik, M., Mizera, A., Manas, M., Hylova, L., Pleva, M.*
Tomas Bata University in Zlín

High-speed cameras are expanding into science laboratories in many disciplines. For example, they can be used for monitoring of the impact testing course, widely spread in evaluation of materials. Usually, they exhibit a slight delay between the trigger pulse was applied and the recording was started. For many applications, this delay may be critical. The authors of this paper have faced two problems: the need to determine the delay in total and the need to check whether it varies in time or not. Therefore, the hereby described device was designed. It allows measurement of the delay of the camera's start in the range from 1 to 999 ms with the step of 0.1 ms.

Poster: 34
**Studying the Chemiresistor Platform Properties**
*Fišer, L., Kadlec, K., Herbst, J.*
University of Chemistry and Technology Prague

In order to make a research of chemiresistors, having a suitable platform, on which we can create and measure studied layers is necessary. Standard sensors are built upon ceramic base equipped with electrodes and heating or tempering elements. Here at our department, we are currently making transition to a KBI2 platform made by Tesla Blatná, because at this time it is the only available one. Main purpose of this paper is mapping its properties, especially the homogeneity of temperature of the chip and overall its dynamic thermal properties. This platform was connected into the heating circuit and readouts of its internal temperature sensor (Pt1000) were evaluated, the temperature was also observed using an thermal imager FLIR T 400 with a macro flyleaf. Calibration of thermal camera is also discussed as well, as determination of each area emissivity. The main result is description of temperature layout all over the chip of the platform and its step responses measured out of thermographical videos taken when the heating was switched on. These data can be further used as base for temperature regulation circuits design. Also quantification of uncertainties of the internal temperature sensor and temperature gradients, which cannot be neglected during sensor layer evaluation, is based upon these data. In the acquired data, symmetrical temperature layout by longitudinal axis is observed. Problems are seen in gradient over the chips length, for operating temperature 300 °C can this difference reach up to 100 °C.

Poster: 35
**On Distributed Discrete-time Kalman Filtering in Large Linear Time-invariant Systems**
*Filasová, A., Krokavec, D.*
Technical University of Košice

The paper is concerned with the problem of distributed Kalman Filtering for discrete-time linear large-scale systems with decentralized sensors. Using the standard approach to the centralized Kalman filtering, the problem of distributed filtering is introduced, given the incidence of additive recurrence to realize such problem. The obtained solutions support the residual signal generation using Kalman filter innovations in the model-based fault detection design. The results, offering structures for fault detection filter realization, are illustrated with a numerical example to note the effectiveness of the approach.

Poster: 36
**Position Control of Servo Drive with a State Observer**
*Bélai, I., Huba, M.*
Slovak University of Technology in Bratislava

The paper is dedicated to the design and comparison of properties of the positional servo drive with two control structures. PD controller and a state observer are used in both. But the presented structures differ in type of state observer. The state observer in the first control structure contains a disturbance observer with an inverse model of plant and the filters of the position and velocity signals (DO-FPID control). The order of filters in the disturbance observer and the feedback is optional. The state observer of the second structure includes an extended state observer (ESO),

which also filters the position and velocity signals, but the order of filters is not optional and it is given by the structure of ESO (ESO-PID control). In addition, the setpoint feedforward is utilised in both structures. The purpose of the feedforward is to minimize the control error during continuous change of position reference. The tuning of controller parameters, state observer and feedforward is presented in the paper. The properties of the position control loop were verified through simulations.

Poster: 37

**Advanced Process Control Design for a Distillation Column Using UniSim Design**

*Oravec, J., Bakošová, M., Artzová, P.*
Slovak University of Technology in Bratislava

The paper addresses implementation of advanced predictive control (APC) for a distillation column. The APC controller was designed using Profit Design Studio software. The distillation column was modeled and the closed-loop control was implemented in UniSim Design environment. The distillation column was handled as a multiple-inputs and multiple-outputs system. Moreover, constraints on the controlled and manipulated variables were considered. APC controller ensured good control performance.

# Pl-Th-1
# Plenary lecture

Chairman: *Kvasnica, M.*

08:30: **Constructive Nonlinear Dynamics in Optimisation and Process Systems**

*Mönnigmann, M.*
Ruhr-Universität Bochum

Model based optimization is common practice in process systems and control engineering. Nonlinear programming, for example, can be applied to find economically optimal steady states, if a system model (such as a set of nonlinear ODE) is available. However, optimization naturally drives dynamical systems to their limits. This may result in modes of operation that are optimal economically, but unstable, or that are optimal but have other undesirable dynamical properties. An approach is presented that integrates stability boundaries and related boundaries into nonlinear programming. These boundaries cannot be treated as simple constraints in nonlinear programs, because they are hidden in the model and therefore no explicit characterization exists for them. Essentially, the critical boundaries of interest are manifolds of bifurcation points, and the distance of any candidate optimal point to these manifolds can locally be described with normal vectors. The approach has successfully been applied to the steady state and periodic mode optimization of nonlinear ODE, discrete time systems and delay differential equations with uncertain parameters. It is illustrated with examples from energy systems, chemical and biochemical engineering.

# Le-Th-2
# Lectures: Model Predictive Control

Chairman: *Skogestad, S.; Belda, K.*

09:30: **Economic NMPC for Heat-Integrated Chemical Reactors**

*Straus, J., Skogestad, S.*
Norwegian University of Science and Technology

This paper presents the application of economic NMPC for a heat-integrated chemical reactor. The chosen case study is given by the ammonia synthesis reactor. Through the application of economic NMPC, it is possible to move the operating point close to the unstable region, corresponding to a 12% increase in the extent of reaction with nominal operations conditions. As a further advantage, the increased conversion of ammonia corresponds to a higher outlet temperature of the system which can be utilized to produce high and medium pressure steam. The proposed economic NMPC is able to adjust in the case of disturbances fast to the new optimal conditions and maintains the productivity of the reactor without engaging into limit-cycle behaviour or extinction of the reactor.

09:50: **Combined Flow and Pressure Control for Industrial Pumps with Simple Adaptive MPC**

*Leonow, S., Wollenhaupt, F., Mönnigmann, M.*
Ruhr-Universität Bochum

We show a simple adaptive linear MPC is suitable to simultaneously control flow rates and pressures in hydraulic processes over wide operating ranges. The predictive controller is adaptive in that the nonlinear process model is re-linearized whenever setpoint changes occur. While its implementation is hardly more complicated than for linear MPC and no additional signals or observers are required, the adaptive controller improves the performance considerably. We apply the proposed approach to the simultaneous flow rate and pressure control for a side-channel pump, and compare it to standard linear MPC and multivariate PID control by applying all three methods to a laboratory setup. As a side-effect, the paper contains a nonlinear model of a side-channel pump and process that is suitable as a benchmark for other control concepts. In contrast to centrifugal pumps, models of this type are not available in the literature for side-channel pumps to the knowledge of the authors.

10:10: **Nonlinear Hierarchical Building Zone and Microgrid Control based on Sensitivity Analysis**

*Lesic, V., Vašak, M., Martinčević, A., Novak, H.*
University of Zagreb

Model predictive control has proven to be a promising platform for complex systems management and energy efficiency improvement in a large number of applications, particulary prominent in building climate or smart grids control. Interoperation of those systems often turns out to be of nonlinear nature. The paper proposes a modular coordination mechanism between building zones comfort control and building microgrid energy flows control based on nonlinear model predictive control. The modularity of coordination implies technology separation with interaction through consumption profiles and equivalent prices, where nonlinearity occurs in electricity-heat energy conversion. A method based on sensitivity analysis is exploited and put to parametric formulation to tackle the problem of high computational complexity. The nonlinearity is addressed by choosing the convergence of the local optimum towards the microgrid global optimum in the direction of the lowest cost function values. Iterative approach between zone and microgrid level nonlinear problem finally results in the cost-optimal zone level operation. Results show the ability of proposed approach to cope with system nonlinearities and illustrate how introduction of a central chiller unit characteristic rises the overall cost benefit of the system.

10:30: **C Code Generation Applied to Nonlinear Model Predictive Control for an Artificial Pancreas**

*Boiroux, D., Jørgensen, J.B.*
Technical University of Denmark

This paper presents a method to generate C code from MATLAB code applied to a nonlinear model predictive control (NMPC) algorithm. The C code generation uses the MATLAB Coder Toolbox. It can drastically reduce the time required for development compared to a manual porting of code from MATLAB to C, while ensuring a reliable and fairly optimized code. We present

an application of code generation to the numerical solution of nonlinear optimal control problems (OCP). The OCP uses a sequential quadratic programming algorithm with multiple shooting and sensitivity computation. We consider the problem of glucose regulation for people with type 1 diabetes as a case study. The average computation time when using generated C code is 0.21s (MATLAB: 1.5s), and the maximum computation time when using generated C code is 0.97s (MATLAB: 5.7s). Compared to the MATLAB implementation, generated C code can run in average more than 7 times faster.

11:10: **Trajectory Planning and Following for UAVs with Nonlinear Dynamics**
*Janeček, F., Klaučo, M., Kvasnica, M.*
Slovak University of Technology in Bratislava

In this paper, we introduce a Matlab-based toolbox called OPTIPLAN, which is intended to formulate, solve and sim- ulate problems of obstacle avoidance based on model predictive control (MPC). The main goal of the toolbox is that it allows the users to simply set up even complex control problems without loss in efficiency only in few lines of code. Slow mathematical and technical details are fully automated allowing researchers to focus on problem formulation. It can easily perform MPC based closed-loop simulations followed by fetching visualizations of the results. From the theoretical point of view, non-convex obstacle avoidance constraints are tackled in two ways in OPTIPLAN: either by solving mixed-integer program using binary variables, or using time-varying constraints, which leads to a suboptimal solution, but the problem remains convex.

11:30: **Predictive Control of 5 DOF Robot Arm of Autonomous Mobile Robotic System**
*Belda, K.*[1] *, Rovný, O.*[2]
[1] Czech Academy of Sciences
[2] Slovak University of Technology in Bratislava

The paper deals with a design of model predictive control (MPC) as an example of the advanced local motion control of articulated robot arms in the scope of manipulation operations within the intradepartmental transportation among workplaces. Initially, the use of articulated robotic arms as a part of mobile robotic systems is discussed. Then, the convenient composition of mathematical models of kinematics and dynamics of the aforementioned robot arms is introduced. Thereafter, MPC design is explained. The proposed theoretical methods of the mathematical modeling and control design are demonstrated by the simulation of the 5 degrees of freedom robot arm composed of drive, joint and arm modules of the Schunk Co.

11:50: **Predictive Control of the Magnetic Levitation Model**
*Rušar, L., Krhovjak, A., Bobál, V.*
Tomas Bata University in Zlín

This paper presents a possible way to control the a very fast nonlinear systems. The system of the magnetic levitation was chosen as an exemplar process. This is an example of the process with a sampling period in order of milliseconds. We chose a predictive control method to control this system. The state-space CARIMA mathematical model is used for prediction of the output values. This paper describes the magnetic levitation model, its linearization, prediction of the output

values and a calculation of the control signal by using a predictor-corrector method which turned out to be the best solution out of the selected ones. The results compare several optimization methods to achieve the fastest calculation of the control signal. All of the simulation was done in Matlab.

12:10: **Temperature Control of Multidimensional System Using Decoupled MPC Controllers**
*Kurilla, J.*
Slovak University of Technology in Bratislava

This paper presents the connection between predictive control and simplification of MIMO system. A model of a part of administrative building is used to observe mutual thermal interactions between individual offices. Multivariable sixth-order system is converted into six linear mutually individual systems of first-order by input-output linearization (decoupling). These SISO systems are controlled by predictive a controller focusing on the accuracy of the room temperature respecting office occupancy profile. Included constraints make from control task the problem of quadratic programing. The final control structure takes advantage of the low computational burden of simple predictive controller and network communication, which ensures the inclusion of constraints. The mutual effect of the output variables and time response of control action is compared in a simulation study.

# Le-Th-3
# Lectures: Invited Industrial Lectures
Chairman: *Čirka, Ľ.*

09:30: **A New Advanced Fully-Features Control System Platform for General Public**
*Prochazka, H.*
PROSYSTEMY, s.r.o.

A new advanced universal control system platform available to general public is presented. General motivation for development of a new control system platform arose from a frustrating experience of coming from control system research into a standard industrial and building management control environment. Advanced control design techniques and algorithms are not commonly applied in practice, nor control research and development tools such as Matlab or Scilab. Smaller implementation companies and independent professionals carrying a few projects a year, not mentioning students or hobbyists, have an additional permanent issue - cost of corporate-built control platform software and hardware. All that reasons led to decision to develop a new advanced fully-featured but low-cost and open-source based control system platform. A platform that blends necessary industrial requirements, advanced control tools, modern open-source and free IT platforms, low-cost hardware. A platform available at low cost to any individual or institution developing simple embedded control or highly complex large process control solution. Note, that by control system platform is meant a complete hardware/software setup for building control systems. A setup that includes real-time controllers, supervisory control and data acquisition (SCADA) system, and tools for real-time control design, validation, optimization, and programming. Considered to-be-controlled technology ranges from a small stand-alone mobile device,

through a compact technology such as chiller or molding machine up to a large process.

09:50: **ProCS - Presentation of Company and our Industrial Applications**
*Keseli, R.*
Actemium Slovakia

ProCS, s.r.o. is a member of the international Actemium network since January 1st, 2015. The Actemium network brings together 300 various business units from various regions of the world that belong to the VINCI Energies group. The business units that are grouped under the Actemium brand are focused on clients from the industry sector. ProCS, s.r.o. as a member of the international Actemium network, helps improve industrial performance in the form of supplying a broad range of services and system solutions in the field of industrial automation and electrical systems to its clients.

10:10: **Yokogawa Approach to Field Wireless Communications**
*Schulcz, J.*
YOKOGAWA Europe

The presentation shows Field wireless systems which utilize wireless communications networks to link a plant's field devices with its control systems. Yokogawa designs these networks to comply with the ISA100.11a standard. In addition to being highly reliable, suited for a wide range of applications, and expandable, they are compatible with wired communications standards such as FOUNDATION fieldbus, HART, and PROFIBUS. The International Electrotechnical Commission (IEC) approved the adoption of the IEC62734 standard, which is based on ISA100.11a.

10:30: **Yokogawa Training Simulator and Life Cycle Simulation Approach**
*Marosi, L.*
YOKOGAWA Europe

The presentation shows Yokogawa OmegaLand based Operator Training Simulator (OTS). The OTS custom dynamic process model is connected with a stimulated Integrated Control and Safety System (ICSS) of the same type as the ICSS system that is delivered to the actual plant. The OTS provides the operational personnel with a realistic operation of the plant, and also provides the environment for the testing of various operational conditions, including emergency condition, safely. They facilitate training of operational personnel for start-up, emergency shutdowns and normal operation of the production facilities.

# Le-Th-4
# Lectures: Process Optimisation

Chairman: *Latifi, R.*

11:10: **Constrained Multi-rate State Estimator Incorporating Delayed Measurements**

*Chandrakesa Shenoi, S.*[1] *, Srinivasan, S.*[2] *, Amrhein, M.*[2] *, Bonvin, D.*[2] *, Narasimhan, S.*[1]
[1] Indian Institute of Technology Madras
[2] EPFL Lausanne

High frequency and accuracy of concentration estimates play an important role in the on-line optimization and control of chemical reaction systems. Such estimates can be obtained using state estimation methods that fuse frequent (fast) delay-free on-line measurements with infrequent (slow) delayed laboratory measurements. In this paper, we demonstrate how several recent advances made in state estimation can be combined in an on-line recursive state estimation framework by imposing knowledge-based and measurement-based constraints on the state estimates of multi-rate concentration measurements with time-varying time delays. This framework is illustrated using a simulated example for a bacterial batch fermentation of recombinant l.lactis. It is shown that an extent-based formulation gives more accurate estimates than a conventional concentration-based formulation.

11:30: **An Efficient RTO Scheme for the Optimal Operation of Chemical Processes Under Uncertainty**

*Hernandez, R., Bučková, M., Engell, S.*
TU Dortmund

In this contribution, an efficient Real-time Optimization (RTO) scheme for the optimal operation of chemical processes under uncertainty is proposed. This work builds on two recently published iterative robust optimization methodologies: Modifier Adaptation with Quadratic Approximation (MAWQA) and Directional Modifier Adaptation (DMA) and proposes a unified framework where the benefits of both methods are combined. As a consequence, fast convergence to the true plant optimum is achieved despite the presence of plant-model mismatch. The methodology is illustrated by simulation studies of a novel transition metal complex catalyzed process.

11:50: **Power Optimizing Control of Grinding Process in Electromagnetic Mill**

*Ogonowski, S., Ogonowski, Z., Swierzy, M.*
Silesian University of Technology Gliwice

The paper presents optimizing control of the electromagnetic grinding system. The electromagnetic grinding is a complex process, thus formulation of the optimization problem is done in a top-down manner. To do so, the parameters which influence product quality and serves as decision variables are specially selected. The selection follows from environmental analysis of the system and discussion of the dynamics of disturbances which affect the grinding process. The criterion function to be minimized is electrical energy consumption. Algorithms solving optimization problem are described in the paper. The optimizing control performs as adaptive-like system where minimum energy is kept by proper control of the inverter. Control system constitutes an element of SCADA layered structure.

12:10: **Closed-loop Dynamic Optimization of a Polymer Grafting Batch Reactor**

*Bousbia-Salah, R.*[1] *, Lesage, F.*[1] *, Fikar, M.*[2] *, Latifi, M.A.*[1]
[1] University of Lorraine, Nancy
[2] Slovak University of Technology in Bratislava

A dynamic real-time optimization (D-RTO) methodology has been developed and applied to a batch reactor where polymer grafting reactions take place. The objective is to determine the on-line reactor temperature profile that minimizes the batch time while meeting terminal constraints on the overall conversion rate and grafting efficiency. The methodology combines a constrained dynamic optimization method and a moving horizon state estimator within a closed-loop control. The results show very good performances in terms of state estimation, constraints fulfillment and computation load.

# Le-Fr-1
# Lectures: Control Education

Chairman: *Kalúz, M.*

09:30: **Steam Turbine Hardware in the Loop Simulation**

*Reitinger, J., Balda, P., Schlegel, M.*
University of West Bohemia in Pilsen

In this paper, a new tool for teaching purposes is presented. The tool is a low-cost Hardware in the Loop simulation with separated process model and control algorithm on standalone hardware which runs in real-time. In this paper, the simulation is used to control the steam turbine model with shaft and generator, but it can be used on wide range of complex physical models. The used model is evaluated on ramp-up simulation in Simulink, and after that mathematical equations are implemented in Modelica language and exported into Functional Mock-up Unit (FMU). The controlled and control models are both simulated on Raspberry Pi minicomputers in real-time and one can observe the control strategy on the second Raspberry with prepared control task and Human Machine Interface (HMI). Both Raspberries are connected through the Modbus over TCP/IP protocol and one can get familiar with this wide-used communication. Furthermore, there is possibility to control the system, change regulators parameters and handle the trade-off between various performances. Regulation can be operated in so-called island or grid mode. The aim of system control is to comply shaft speed demands described in norms.

09:50: **Virtual Laboratory based on Node.js Technology**

*Stark, E., Bisták, P., Kozák, Š., Kucera, E.*
Slovak University of Technology in Bratislava

The paper demonstrates remote control of test experiment in the virtual laboratory. This is a common problem, but another way can always be used to solve it. The paper compares several existing virtual laboratories and their possible issues at present. To develop such a new solution JavaScript technology was used on both client and server side using Node.js runtime.

10:10: **Real-Time Simulator of Component Models Based on Functional Mock-up Interface 2.0**

*Balda, P.*
University of West Bohemia in Pilsen

This paper deals with a real-time simulator of component models. The simulator imports models compatible with Functional Mock-up Interface for Model Exchange and Co-Simulation 2.0 standard (FMI 2.0) which can be generated from various versions of Modelica (e.g. OpenModelica, Dymola, SimulationX) or from several other tools. The present version of the simulator works with FMI 2.0 Co-Simulation models in which the solver is a part of the exported executable model. The simulator is integrated into RexCore – the real-time control runtime, which allows to simulate the model itself, the model and the control algorithm on the same computer (Software in the Loop, SIL) and also the model on a single computer with physical inputs and outputs connected to outputs and inputs of the second computer for control (Hardware in the Loop, HIL).

10:30: **Design and Development of a Low-cost Inverted Pendulum for Control Education**
*Bakaráč, P., Kalúz, M., Čirka, Ľ.*
Slovak University of Technology in Bratislava

This paper describes the design and development of a low-cost inverted pendulum device for purposes of control education. The device is based on a modular construction in the form of assembly kit. The individual parts can be made of laser cut fiberboard or any appropriate material. The pendulum uses a stepper motor as the actuator for cart movement and rotary encoders for sensing the angle of rod and position of a cart. The main electronics used for control of motor and sensors reading is a micro- controller board with Atmel ATMega2560 8-bit MCU. The paper also describes the principles of operation of the device, along with the communication and external control interface written in MATLAB. The MATLAB command line interface contains a set of simple functions for signal acquisition and control of the main actuator in terms of position, velocity and acceleration. Students can use these to incorporate the device into their own operation algorithms and control scenarios. For educational purposes, the paper also deals with the mathematical modeling of the system and its simplifications that can be applied in the case of stepper motor usage.

# Le-Fr-2
# Lectures: Modelling, Simulation, and Identification of Processes

Chairman: *Ogonowski, Z.*

09:30: **Clustering-based Identification of MIMO Piecewise Affine Systems**
*Hure, N., Vašak, M.*
University of Zagreb

PieceWise Affine (PWA) models are used to approximate general nonlinear dynamics with an arbitrary precision. PWA model can be employed for a constrained optimal controller synthesis, whereas the complexity of the controller is in a large part determined with a complexity of the model. Among the prominent methods for a PWA system identification is the clustering-based identification, which is originally designed for identification of systems with a Multiple-Input Single-Output (MISO) structure. When applied for the Multiple-Input Multiple-Output (MIMO) system identification, previously used clustering-based approach implied independent estimation of PWA maps for each of the outputs, whereas the MIMO PWA model was constructed by merging the polyhedral partitions and parameters of each MISO model. PWA model obtained with the respective approach often contained a significant number of submodels, thus aggravating the controller design process. In this paper we propose a multivariate linear regression approach for the identification of a MIMO PWA model based on the clustering technique. The presented approach is a systematic extension and fully exploits all benefits of the clustering-based identification. The proposed approach is validated on a coupled MIMO system identification problem.

09:50: **Intuitionistic Fuzzy Radial Basis Functions Network for modeling of nonlinear dynamics**

*Todorov, Y.*[1] *, Terziyska, M.*[2] *, Koprinkova-Hristova, P.*[3]
[1] Aalto University, Helsinki
[2] University of Food Technologies, Plovdiv
[3] Bulgarian Academy of Sciences

This paper describes a design methodology for a neural network with improved robust qualities in notion to handling uncertain input data space variations. The proposed network topology combines the simplicity the radial basis functions networks to interpret or classify data pairs and the abilities of the intuitionistic fuzzy logic to deal with the vagueness of the data space. As a learning approach for the designed hybrid neural network, the gradient optimization procedure is proposed. To investigate the potentials of the generated structure throughout varying network parameters, the modeling of a twobenchmark chaotic time series – Mackey-Glass and Rossler under uncertain conditions is investigated. The obtained results prove the flexibility of the approach and its potentials to cope with data variations.

10:10: **Novel Tools for Model-based Control System Design based on FMI/FMU Standard with Application in Energetics**

*Čech, M., Königsmarková, J., Reitinger, J., Balda, P.*
University of West Bohemia in Pilsen

The paper presents novel tools for model-based control system design based on FMI/FMU standard (Functional Mock-up Interface / Unit). It is focused on application of FMI standard for easy integration of control system development cycle starting with Model-in-the-Loop (MIL) simulation and finishing with Hardware-in-the-Loop (HIL) simulation. It is shown, how the Functional Mock-up Units (FMU) containing dynamic differential-algebraic equations of various parts of the device (mechanical, electrical, hydraulic, thermal, etc.) can be easily deployed to unified simulation environment where the control system is designed, consequently. The procedure allows to combine inputs from various Modelica-based tools at the process model side, utilizing power of Matlab/Simulink for design, analysis and optimization of control system and perform final test via HIL scenario where both the model and control system are simulated in real-time on separated HW units. The pros and cons of both FMI concepts, i.e. Co-Simulation and Model Exchange are discussed in detail. The whole procedure is demonstrated on a steam turbine example combining component based and equation based modeling. Both the turbine model and the full control loop are validated in all phases of control system development. It is shown, that monolithic simulation block with proprietary solver reduces computational burden compared to automatic FMU concept.

10:30: **Offset-Free Hybrid Model Predictive Control of Bispectral Index in Anesthesia**

*Ingole, D., Drgoňa, J., Kvasnica, M.*
Slovak University of Technology in Bratislava

This paper deals with the anesthesia control, using bispectral index (BIS) as a measure of the depth of anesthesia; controlled by hybrid model predictive control strategy. The piecewise affine (PWA) hybrid pharmacodynamic model of a patient containing a set of local linear dynamics is used to

describe the relationship between BIS value and drug infusion rate. The hybrid model predictive control problem is formulated as a mixed integer quadratic programming (MIQP) problem and solved online. Furthermore, a disturbance observer is designed for the offset-free BIS reference tracking. The results of designed controller intended for reference tracking, disturbance rejection and constraint handling are presented. Moreover, the performance of nonlinear MPC is compared with the hybrid MPC and is shown to be computationally less complex and fast.

# Le-Fr-3
# Lectures: Industrial Automation

Chairman: *Rosinová, D.*

11:10: **Legal Aspects of Autonomous Vehicles – an Overview**

*Ilková, V.*[1] *, Ilka, A.*[2]
[1] Comenius University in Bratislava
[2] Chalmers University of Technology

The main goal of this article is to provide up-to-date information about legal regulation of autonomous vehicles (AVs) in Europe and the United States of America (U.S.). The legal overview is primarily intended for technical professionals for the purpose of giving them a holistic approach to AVs. The authors believe that technical professionals have to be aware of legal regulation of AVs as well in order to get the opportunity to discuss the feasibility of different legal statements. Besides the definition of AVs based on levels of automation, the article also contains answers to following questions: What are the greatest benefits of AVs? How does the general road traffic law need to be changed to allow the use of AVs on public roads? What are the differences between the current state of AV regulations in the U.S. and Europe? Finally, the paper draws attention to the most significant legal challenges that AVs address to lawmakers, insurance companies, consumers, and last but not least, car manufacturers.

11:30: **Adaptive Control of Distillation Column Using Adaptive Critic Design**

*Koprinkova-Hristova, P.*[1] *, Paraschiv, N.*[2] *, Olteanu, M.*[2] *, Todorov, Y.*[3] *, Terziyska, M.*[4]
[1] Bulgarian Academy of Sciences
[2] Petroleum-Gas University of Ploiesti
[3] Aalto University, Helsinki
[4] University of Food Technologies, Plovdiv

The paper aims at synthesis of an adaptive controller of the distillate output flow rate of a binary distillation column. The disturbance of the process is the change of concentration of the inlet compound. The Adaptive Critic Design (ACD) approach was applied to predict on time the future effect of disturbance and to adapt the distillate output flow rate in order to prevent deviations from the desired distillate concentration. The key element of ACD – the critic – is a fast trainable recurrent neural network named Echo state network (ESN). The simulation investigations demonstrated that the proposed adaptive control scheme outperforms a classical non-adaptive controller with respect to the settling time and the reaction delay.

11:50: **Proposal of System for Automatic Weld Evaluation**
*Haffner, O., Kucera, E., Kozák, Š., Stark, E.*
Slovak University of Technology in Bratislava

The paper deals with the development of a system for automatic weld recognition using new information technologies based on cloud computing and single-board computer in the context of Industry 4.0. The proposed system is based on a visual system for weld recognition, and a neural network based on cloud computing for real-time weld evaluation, both implemented on a single-board low-cost computer. The proposed system was successfully verified on welding samples which correspond to a real welding process in the car production process. The system considerably contributes to the welds diagnostics in industrial processes of small- and medium-sized enterprises.

12:10: **Extremal Problems for Time Lag Parabolic Systems**
*Kowalewski, A., Miśkowicz, M.*
AGH University of Science and Technology

Extremal problems for time lag parabolic systems are presented. An optimal boundary control problem for distributed parabolic systems in which constant time lags appear in the state equations and in the boundary conditions simultaneously is solved. Such equations constitute in a linear approximation a universal mathematical model for many processes of optimal heating. The time horizon is fixed. Making use of the Dubovicki-Milutin scheme, necessary and sufficient conditions of optimality for the Neumann problem with the quadratic performance functionals and constrained control are derived.

# Le-Fr-4
# Lectures: Applications and Case Studies
Chairman: *Oravec, J.*

11:10: **Viability Assessment of a Rigid Wing Airborne Wind Energy Pumping System**
*Licitra, G.*[1] *, Koenemann, J.*[1] *, Horn, G.*[2] *, Williams, P.*[3] *, Ruiterkamp, R.*[3] *, Diehl, M.*[4]
[1] University of Freiburg & Ampyx Power B.V.
[2] Kitty Hawk
[3] Ampyx Power B.V.
[4] University of Freiburg

Airborne wind energy (AWE) is an emerging technology that is capable of harvesting wind energy by flying crosswind flight patterns with a tethered aircraft. Nowadays, several companies are trying to scale-up their concept in order to be competitive in the energy market. However, the scaling process requires several iterations and trade-off among the different components in terms of requirements that have to satisfy both technological and economical viability. In this paper, we show how to deal with this task by means of an optimal control approach combined with statistical analysis based on the established methods for conventional Wind Energy Conversion Systems. This approach is applied to a rigid wing pumping mode AWE System (AWES) built by Ampyx Power B.V..

11:30: **Design of Robust MPC with Integral Action for a Laboratory Continuous Stirred-Tank Reactor**
*Oravec, J., Bakošová, M., Hanulová, L., Horváthová, M.*
Slovak University of Technology in Bratislava

The paper presents a design of the robust model predictive control (RMPC) for a laboratory continuous stirred-tank reactor (CSTR). A neutralization reaction ran in the CSTR, and the reactants were acetic acid and sodium hydroxide. The controlled variable was pH of the reaction mixture. The control input was the volumetric flow-rate of the base. The system was modeled using experimental data of several step-responses. Measurement noise was reduced using the Hebky filter. The robust model-based control strategy was implemented to assure good control performance. The offset-free reference tracking was ensured by the implementation of RMPC with integral action.

11:50: **Dynamic Compensator for Reference Tracking Realized on FPGA**
*Kozáková, A., Kocúr, M.*
Slovak University of Technology in Bratislava

The paper deals with a practical implementation of a digital observer-based reference tracking state controller for a laboratory plant. The state controller is designed to track reference commands that can be described by linear differential equations with constant coefficients; this type of controller is known as Command Generator Tracker (CGT) [1]. The resulting dynamic compensator is implemented to control speed of a laboratory plant using FPGA.

12:10: **Stability Analysis of Wave Based Control: Practical Aspects**
*Langmajer, M., Schlegel, M., Šetka, V.*
University of West Bohemia in Pilsen

The wave-based control system has a potential to become effective method of vibration-damping controller design. The only design requirement of this method is to absorb the returning wave by the actuator. Stability or performance of the overall system is not included in the design specifications and the approach does not provide it in general. The advantage of this approach is that it does not need sensors along the entire length of system and it can simultaneously control position and damps vibration. On the other hand, this method is relatively young and there are many areas of research that have to be explored. This paper brings the stability analysis of wave based control for homogeneous chains. The paper also presents some remarks that extend obtained result for distributed systems.

# Author Index

# List of Participants

## Bulgaria

**Koprinkova-Hristova**, Petia, Sofia, Institute of Information and Communication Technologies, Bulgarian Academy of Sciences

## China

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