# SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

## FACULTY OF CHEMICAL AND FOOD TECHNOLOGY

### INSTITUTE OF INFORMATION ENGINEERING, AUTOMATION AND MATHEMATICS

# DEPARTMENT OF INFORMATION ENGINEERING AND PROCESS CONTROL

STU FCHPT

ANNUAL REPORT

2015

Address:

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Institute of Information Engineering, Automation and Mathematics

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From left: B. Takács, M. Jelemenský, J. Holaza, M. Kvasnica, A. Vasičkaninová, K. Macušková, J. Števek, J. Oravec, M. Klaučo, M. Fikar, A. Kalmárová, R. Valo, A. Sharma, Ľ. Čirka, M. Kalúz, J. Drgoňa, S. Vagač

Missing: M. Bakošová, D. Ingole, A. Mészáros, J. Mikleš, D. Pakšiová, R. Paulen

# Contents

# 1 Preface

Department of Information Engineering and Process Control has at the Faculty of Chemical and Food Technology of the Slovak University of Technology in Bratislava more than fifty-year tradition. In the frame of the bachelor study program Information Engineering, Automation and Management in Chemical and Food Industry and the master study program Information Engineering and Automation in Chemical and Food Industry, it educates high-qualified specialists in the field of process control for design, implementation and application of control systems.

Nowadays, information technologies and process control with using microprocessor based control technique represent important and acknowledged scientific branches. These branches more and more influence the economic and social growth in the whole world and successively also in Slovakia. The chemical, food and pharmaceutical industries with their technologies are no exceptions. No technology is able to be successful in the competition without optimization and advanced control systems or without using information technologies. In the connection with these facts, all our graduates have found their jobs without problems during the whole history of the department. It confirms also, that the education of the specialists in the information engineering and process control has been very attractive and its significance is even growing. The graduates of the department do well not only in the companies and institutions oriented on design and supplying of control systems for various technologies but also in the bank sector and they found their own firms respectively. Teaching and research activities of the department are oriented on process control, identification and modeling of systems, adaptive control, construction and testing of measuring devices and equipment, and on development of software packages for intelligent control systems. Second branch is devoted to information technologies, data management, and programming.

prof. Ing. Miroslav Fikar, DrSc.

# 2 Introduction

This report summarizes the teaching and research activities at the Department of Information Engineering and Process Control at the Faculty of Chemical and Food Technology at the Slovak University of Technology in Bratislava during the period January 1 – December 31, 2015.

Department of Information Engineering and Process Control of the FCFT STU in Bratislava was constituted from the Department of Measuring and Control Technique of the Faculty of Electrical Engineering of the Slovak University of Technology in Bratislava in 1962. Because of the specific control problems of the processes and systems in the chemical and biochemical technologies, the specialization Process Control in the frame of the study branch Chemical Engineering and Process Control has been established. Students and postgraduate students have been educated since 1964. So far, more than four hundreds specialists and almost thirty PhD students have been graduated here and three professors and nine associated professors have been appointed. Since 2005, Department of Information Engineering and Process Control and Department of Mathematics have formed Institute of Information Engineering, Automation, and Mathematics.

The first head of the department was Prof. Daniel Chmúrny, DrSc in 1962 – 1986. Prof. Ján Mikleš, DrSc headed the department in 1986 – 1994 and in 1998 – 2003. The head in 1995 – 1997 was Assoc. prof. Alojz Mészáros, PhD and prof. Ing. Miroslav Fikar, DrSc. has headed the department since 2003.

Department of Information Engineering and Process Control is one of the 22 departments at the FCFT STU, where students obtain specialization in various branches of chemical technology or chemical engineering. Approximately 1000 students are currently enrolled in the three-year bachelor programs leading to the Bc. degree and two-year master programs leading to the Ing. degree, which is equivalent to the MS degree. The best of them continue in the four-year doctor programs leading to the PhD degree. Three study programs are guaranteed by the Department of Information Engineering and Process Control: bachelor study program Automation, Information Engineering and Management in Chemical and Food Technologies, master study program Automation and Information Engineering in Chemical and Food Technologies and PhD study program Process Control.

# 3 Staff

## 3.1 Head of the Department

| | |
|---|---|
| prof. Ing. Miroslav Fikar, DrSc. | Telephone: ++ 421 – 2 – 59 325 367<br>E-mail: head@kirp.chtf.stuba.sk |

## 3.2 Full Professors

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| prof. Ing. Miroslav Fikar, DrSc. | Telephone: + 421 – 2 – 59 325 367<br>E-mail: miroslav.fikar@stuba.sk |
| prof. Ing. Alajos Mészáros, PhD. | Telephone: + 421 – 2 – 59 325 149<br>E-mail: alajos.meszaros@stuba.sk |
| prof. Ing. Ján Mikleš, DrSc. | Telephone: + 421 – 2 – 59 325 343<br>E-mail: jan.mikles@stuba.sk |

## 3.3 Associate Professors

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| doc. Ing. Monika Bakošová, CSc. | Telephone: + 421 – 2 – 59 325 353<br>E-mail: monika.bakosova@stuba.sk |
| doc. Ing. Michal Kvasnica, PhD. | Telephone: + 421 – 2 – 59 325 352<br>E-mail: michal.kvasnica@stuba.sk |

## 3.4 Assistant Professors

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| Ing. Ľuboš Čirka, PhD. | Telephone: + 421 – 2 – 59 325 355<br>E-mail: lubos.cirka@stuba.sk |
| Ing. Anna Vasičkaninová, PhD. | Telephone: + 421 – 2 – 59 325 362<br>E-mail: anna.vasickaninova@stuba.sk |
| Ing. Richard Valo, PhD. | Telephone: + 421 – 2 – 59 325 730<br>E-mail: richard.valo@stuba.sk |
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| Ing. Juraj Števek, PhD. | Telephone: + 421 – 2 – 59 325 364<br>E-mail: juraj.stevek@stuba.sk |

## 3.5 Researchers

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| Ing. Radoslav Paulen, PhD. | Telephone: + 421 – 2 – 59 325 730<br>E-mail: radoslav.paulen@stuba.sk |
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## 3.6 PhD Students

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## 3.7 Technical staff

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| Andrea Kalmárová | Telephone: + 421 – 2 – 59 325 363<br>E-mail: andrea.kalmarova@stuba.sk |

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| Katarína Macušková | Telephone: + 421 – 2 – 59 325 366<br>E-mail: katarina.macuskova@stuba.sk |

# 4 Teaching and Research Laboratories

**Laboratory of Process Control:**

- Distillation Column Armfield UOP3CC
- Membrane Process
- Multifunction Station Armfield PCT40
- Hydraulic System with Storage Tanks DTS200
- Training Station Armfield PCT23
- Smallscale Fuel Cell

**Laboratory of Control Systems:**

- MATLAB/Simulink
- Siemens-SIMATIC S-7 200, S-7 1200
- Lego Mindstorms NXT 2.0
- Thermo-optical System uDAQ28/LT
- Ball & Plate CE 151
- Magnetic Levitation

**Laboratory of Industrial Technology:**

- Siemens-SIMATIC S-7 300
- FOXBORO
- B&R
- VIPA 300S
- eWONx005CD, dSPACE
- Experion/Honeywell

**Computer Laboratories:**

- Linux based PCs
- Raspberry Pi
- Arduino
- Moving robots (cars)

**Remote Laboratories:** Control of technological processes via internet access

- Two-tank system
- Thermal-optical systems
- DC motor

# 5 Educational Activities

## 5.1 Bachelor Study

**1st semester (Winter)**

| | | |
|---|---|---|
| Algorithms and Tools for Chemical Engineering Calculations I | 0/0/2 | Kalúz, Števek |
| Fundamentals of Matlab | 0/0/2 | Holaza, Jelemenský, Oravec, Števek |
| Linux – Basic Automation | 0/0/2 | Valo |

**2nd semester (Summer)**

| | | |
|---|---|---|
| Informatisation and Information Systems | 1/0/0/2 | Čirka, Kalúz |
| Operating Systems | 0/0/0/3 | Valo |
| Chemical Engineering Calculation on PC II | 0/0/0/1 | Kalúz, Števek |
| Programming I | 1/0/0/2 | Klaučo, Kvasnica |

**3rd semester (Winter)**

| | | |
|---|---|---|
| Fundamentals of Language C | 0/0/2 | Kvasnica, Takács |
| Modelling | 2/0/3 | Mészáros, Vasičkaninová |

**4th semester (Summer)**

| | | |
|---|---|---|
| Process Control | 2/0/0/0 | Bakošová |
| Laboratory Excercises of Process Control | 0/0/0/2 | Oravec, Sharma |
| Optimisation | 2/0/0/3 | Klaučo, Kvasnica |
| Chemical Engineering Calculation on PC IV | 0/0/0/1 | Števek |
| Programming I | 1/0/0/2 | Kvasnica |

**5th semester (Winter)**

| | | |
|---|---|---|
| Design of Information and Control Systems | 2/0/3 | Kvasnica, Valo |

**6th semester (Summer)**

| | | |
|---|---|---|
| Process Control | 2/0/0/0 | Bakošová |
| Laboratory Excercises of Process Control | 0/0/0/2 | Čirka, Drgoňa, Holaza, Jelemenský, Kalúz, Klaučo, Oravec, Števek, Takács, Vasičkaninová |
| Integrated Control in Process Engineering | 2/0/0/3 | Bakošová, Vasičkaninová |
| Bachelor Project | 0/0/0/10 | Čirka |
| Programming II | 1/0/0/2 | Kvasnica |

## 5.2 Master Study

**1st semester (Winter)**

| | | |
|---|---|---|
| Automatic Control Theory I | 2/0/3 | Fikar, Sharma |
| Control of Technological Processes | 1/0/1 | Bakošová, Vasičkaninová |
| Information Technology I | 0/0/2 | Čirka |
| Modelling in Process Industry | 2/2/0 | Bakošová, Vasičkaninová |
| Process Dynamics and Control | 2/0/1 | Bakošová, Vasičkaninová |
| Programming of Web Applications | 1/0/2 | Čirka |
| Technical Means of Automation | 2/0/2 | Kalúz |

**2nd semester (Summer)**

| | | |
|---|---|---|
| Theory of Automatic Control II | 2/0/3/0 | Čirka, Fikar |

| | | |
|---|---|---|
| Identification | 2/0/2/0 | Čirka, Fikar |
| Industrial Control and Information Systems 1 | 1/0/3/0 | Kvasnica, Valo |
| Semestral Project II | 0/0/3/0 | Čirka |
| Technological Process Control | 1/1/0/0 | Mészáros, Vasičkaninová |

**3rd semester (Winter)**

| | | |
|---|---|---|
| Automatic Control Theory III | 2/0/2 | Fikar, Oravec |
| Creation of Scientific Documents | 0/2/0 | Fikar |
| Information Engineering and Industrial Information Systems II | 2/0/2 | Kvasnica, Sharma |
| Information Technologies II | 0/0/2 | Čirka |
| Optimisation of Processes and Plants | 2/0/2 | Ingole, Kvasnica |
| Predictive Control | 1/2/0 | Kvasnica |
| Process Control Project | 0/0/3 | Števek |
| Project Software Systems | 0/2/0 | Drgoňa, Kvasnica |

**4th semester (Summer)**

| | | |
|---|---|---|
| Robust Control | 2/0/1/0 | Bakošová, Oravec |
| Model Predictive Control | 2/0/1/0 | Klaučo, Kvasnica |

## 5.3 PhD Study

| | | |
|---|---|---|
| Automatic Control Theory | 4/0/0/0 | Mikleš |
| Modelling and Control of Proceses in Chemical Technology | 2/0/0/0 | Bakošová |
| Optimal Control | 2/0/0/0 | Fikar |

## 5.4 Course Contents

### 5.4.1 Lectures in Bachelor Study

**Optimization (2h/week, $4^{th}$ semester)** Introduction to optimization and motivating examples. Classification of optimization problems. Convex functions. Extrema of 1-D smooth functions. Extrema of n-D smooth functions. Analytical methods for unconstrained optimization. Constrained optimization with equality constraints. The Lagrange method for equality constrained optimization. Economic interpretation of Lagrange multipliers. Inequality constrained optimization. Karush-Kuhn-Tucker conditions. Simplex method for linear programming. Quadratic programming. Applications of linear and quadratic programming. Introduction to nonlinear optimization. Introduction to mixed-integer optimization.

**Integrated Control in Process Engineering (2h/week, $6^{th}$ semester)** Feedback and feed-forward control. More complex control structures: cascade control, feed-forward-feedback control, control loop with auxiliary control input, time-delay compensator – Smith predictor, flow-ratio control, special cases of multi-variable control. Process control: control of storage tanks, control of mixing units, control of heat exchangers, control of distillation columns, control of chemical reactors, control of dryers.

**Information and Information Systems**
**(1h/week, $2^{nd}$ and $6^{th}$ semester)** Information system, systems for data processing. Database system structure. Logic data organization methods, database architecture. Means of data defining and manipulation. SQL language. Visualization level of technological and production process control. SCADA/HMI (Supervising Control and Data Acquisition / Human Machine Interface) application design. Professional software packages and components (WinCC, dSPACE/Control Desk, MATLAB/MWS for Windows). Creating HTML application and dynamic web pages bounded to control system databases, SCADA/HMI systems etc.

**Modeling (2h/week, $3^{rd}$ semester)** Fundamentals of chemical process modeling and simulation. Linear and nonlinear state-space models. Mathematical models of selected chemical processes with lumped parameters. Nonlinear and linearized models of a tank and serially connected tanks. Linear and nonlinear models of mixing processes. Mathematical models of processes with heat transfer: recuperative heat exchanger, shell heat exchanger, flow heater. Nonlinear and linearized mathematical models of continuous stirred tank reactors. Dynamic and static behavior of processes.

**Process Control (2h/week, 4th and 6th semester)** Introduction to process control. Modeling of special types of processes of chemical technology. Static and dynamic behavior of controlled systems. Closed loop for control of technological processes. Controllers. Dynamic behavior of closed loops. Stability of systems. Synthesis of controllers. Control of special types of processes of chemical technology. Basic principles of devices and methods for measurement of technological quantities.

**Design of Information and Control Systems (2h/week, 5th semester)** Basic principles and methods for control systems design concerning control aims requirements. Systematic design approach. Utilization of modern software and technical tools for control design. Information control supply.

**Programming I (1h/week, 4th semester)** Basics of programming language C and C++. Programming language description, loops, conditions, methods, fields, basic algorithms and their usage during programs development. Preparation for advanced algorithms in Programming II course.

**Programming II (1h/week, 6th semester)** Students should learn to develop learned basic programming in C/C++. Working with arrays and matrices, initialization and allocation of arrays. Input and output to a file, work with command line. Working with strings and simple data structures. Familiarity with the structures. Design and implementation of custom algorithms.

### 5.4.2 Laboratory Exercises in Bachelor Study

**Fundamentals of Matlab (2h/week, 1st semester)** Introduction to MATLAB and Simulink, variables, expressions, and operators, matrices and vectors, elementary mathematical functions, graphics – 2D, 3D charts, polynomials, custom applications, Simulink.

**Linux – Basic Automation (2h/week, 1st semester))** Scripting language BASH, introduction to scripting, variables, cycles, conditions, more complex tasks, presentation.

**Algorithms and Tools for Chemical Engineering Calculations I (2h/week, 1st semester)** The aim of subject is to prepare students creatively and effectively employ computing technique to solve and present engineering problems in MS Excel environment. Special attention is devoted to problems in the chemical engineering field. They are able to solve basic problems, manipulate with data, present data, to write research text. They are able to solve systems of linear and non linear equations.

**Chemical Engineering Calculation on PC II (1h/week, 2nd semester)** The aim of subject is to prepare students creatively and effectively employ computing technique to solve and present engineering problems in MATLAB environment. Special attention is devoted to problems of the chemical engineering. Upon successful completion of this course, the student will be able to understand MATLAB, and perform matrix operations, solve basic problems, manipulate with data, present data, create dimensional plots, and perform symbolic operations. They are able to solve systems of linear and non linear equations.

**Operating Systems (3h/week, 2nd semester)** Introduction to operating systems of computers. Multitasking, types of multitasking and their comparison. Linux – operation system of UNIX-type, its installation. Free and Open Source Software, GNU Foundation. Introduction to Solaris operating system. Basic file and directory operations, editing, searching, regular expressions, makefiles. Introduction to computer typesetting. Remote computers, communication tools: telnet, ssh, ftp, http, smtp.

**Fundamentals of Language C (2h/week, 3rd semester)** The course introduces students to basic concepts and fundamentals of the C programming language. Covered topics include: allocation of variables, standard output to screen, standard input from the keyboard, string functions, if-then-else conditions, FOR and WHILE loops, arrays, matrices and user-defined functions. Each covered topic is accompanied with illustrative examples and sample problems for practicing.

**Chemical Engineering Calculation on PC IV (1h/week, 4th semester)** The aim of subject is to prepare students creatively and effectively employ computing technique to solve and present engineering problems MATLAB environment. Special attention is devoted to problems in the chemical engineering field. Students are able to formulate engineering problems as mathematical models belonging to one of the following categories: ordinary differential equations and systems of equations, numerical solution of partial differential equations, linear and nonlinear regression and optimisation.

**Laboratory Exercises of Process Control (2h/week, 4th and 6th semester)** MATLAB/Simulink as a simulation tool for LEPC. Laplace transform as a mathematical tool for LEPC. Input-output description of dynamic systems, transfer functions, poles and zeros. Step responses and impulse responses of dynamic systems. Mathematical models and dynamic behavior of processes of chemical technology. Feedback control. PID controllers and their properties in feedback control. Controller synthesis and control of processes of chemical technology.

**Laboratory Exercises of Information Engineering and Systems (1h/week, 6th semester)** Introduction to information systems and technologies. Electronic computers, computer software and computer networks. Internet. Language XHTML a CSS. Installation and setting of the software for programming (Apache, PHP, MySQL). Principles of programming language PHP. Work with databases.

**Bachelor Project (10h/week, 6th semester)** The students can creatively solve problems related to the specified topic. They can do literature search and read and understand the available technical literature in Slovak and English. They are able to apply the knowledge acquired during their studies. They can plan and execute experiments. They are able to evaluate the achievements and make conclusions. They can prepare a written documentation of solving the problem and the results obtained. The students are able to defend their results.

### 5.4.3 Lectures in Master Study

**Programming of Web Application (1h/week, 1st semester)** PHP language a SQL database systems basics. Internet programming. Process or other database sources data and measurement processing.

**Control of Technological Processes (1h/week, 1st semester)** The students have become familiar with basic principles of identification from aperiodic or periodic step responses. The know principles of feed-back and feed-forward control. They know principles of process control using complex control structures. They know principles of control using simple and complex control structures that are implemented for control of selected processes from the chemical industry.

**Technical Means of Automation (2h/week, 1st semester)** Continuous-time controllers, types and their static and dynamic behavior. Discrete controllers, their dynamic behavior and using in control loops. PC in the role of a controller. Servo-drives for electric and pneumatic control system. Control valves. Digital devices. Logic functions, electric devices for realization of logic functions. Sequence loops. Hardware for control of technological processes. Analogue input modules, A/D, D/A converters. Digital input modules. Sources of inaccuracies in control loops.

**Modeling in Process Industries (2h/week, 1st semester)** Introduction to modeling in process engineering, modeling of processes with discretely and continuously distributed parameters: tubular heat exchangers, tray distillation columns, packed distillation columns, packed absorption columns; modeling of extractors without and with chemical reactions; modeling of tubular chemical reactors without and with catalyst; modeling of batch and semi-batch processes: chemical reactors, extractors and distillation columns.

**Automatic Control Theory I (2h/week, 1st semester)** State-space process models. Stability, controllability, observability of continuous-time systems. Input-output process models. Lyapunov stability. Frequency analysis. Bode plot. Nyquist plot. Gain and phase margins. State feedback and state observers. Algebraic control design.

**Process Control and Dynamics (2h/week, 1st semester)** Introduction to control of technological processes. Principles of control of technological processes: feedback and feed-forward control. Simple feedback control loop.

Methods for PID controller tuning. Complex control loops: time-delay compensation (Smith predictor), cascade control, feed-forward compensation of disturbances, flow-ratio control. Control of tanks, control and controlled variables. Control of heat exchangers, controlled and control variables, control loops. Control of distillation and absorption columns, controlled and control variables, control loops. Control of chemical reactors, controlled and control variables, control loops. Basic principles of devices and methods for measurement of technological quantities: liquid level, temperature, pressure, flow rate, concentration.

**Industrial Control and Information Systems I (2h/week, 2$^{nd}$ semester)** Basic principles and stages of industrial information system design. System reliability and diagnostics. Projecting and control design of selected technologies using an appropriate software. PLC systems and Profibus. WinCC visualization tools. Programming with use of ladder logic, state list, and function block diagrams.

**Identification (2h/week, 2$^{nd}$ semester)** The identification of dynamic systems from their step responses of the 1st and 2nd order, Strejc, Šalamon, Hudzovič, Söderström methods. Statistical identification methods. Classification of models for experimental identification. Least-square method, recursive least- square method, lemma about the matrix inversion, REFIL, LDFIL, LDDIF algorithms. Prediction error method and auxiliary variable method. Using of recursive identification methods for identification of multi-variable and continuous-time systems. Aspects of the least square method and identification of static models, passive and active experiment.

**Automatic Control Theory II (2h/week, 2$^{nd}$ semester)** State-space discrete-time models. Input-output discrete-time models. Controllability and observability of discrete-time systems. Direct digital control. Stability of discrete-time systems. Discrete-time feedback systems. Optimal control and principle of minimum. LQ control. Dynamic programming. Optimal observers and state estimation. Kalman filter.

**Technological Process Control (1h/week, 2$^{nd}$ semester)** The students have become familiar with basic principles of identification from aperiodic or periodic step responses. The know principles of feed-back and feed-forward control. They know principles of process control using complex control structures. They know principles of control using simple and complex control structures that are implemented for control of selected processes from the chemical industry.

**Information Technologies II (1h/week, 3rd semester)** Syntax of PHP language and its applications. Program structure, data types, constants, string operations, logic operators. Control structures – conditions, if-then-else statement, loops. Connection with database – searching, selecting, updating, database functions, forms, control and data elements on the web page. An example of design of final web application for working with database.

**Automatic Control Theory III (2h/week, 3rd semester)** Adaptive Control: self-tuning and MRAC. Advanced process control: heat exchangers, distillation columns, waste-water treatment plants, crystallization, combustion, neutralization, chemical reactors. MIMO control: RGA, decoupling, MPC

**Industrial Control and Information Systems II (2h/week, 3rd semester)** The aim of this course is to teach students to work with industry information systems. The principles and means of communication in the design of information and communication systems: XML, DTD, XML Schema, Xpath, XSLT, SVG.

**Optimization of Processing and Production (2h/week, 3rd semester)** Introduction to optimization of production systems with motivating examples. Analytical methods for unconstrained optimization. Numerical methods for unconstrained optimization. Gradient-free unconstrained optimization methods. Equality constrained optimization. Feasible and infeasible-start Newton methods. Inequality constrained optimization, Karush-Kuhn-Tucker conditions. Complexity of optimization methods. Linear and quadratic programming with applications. Active set methods. Separation and classification problems. Integer optimization, formulation of mixed-integer optimization problems. Logic and mixed constraints. Algorithms for integer optimization.

**Model Predictive Control (2h/week, 4th semester)** Introduction to principles of the predictive control, types of models and objective functions. Formulation of a problem as the optimization problem with aim to predictive control of the chemical technology systems. Introduction to predictive control and definition of the main terms. Explanation of the norms and their application in LP and QP problems. Construction of the optimization problems and their implementation in YALMIP. State-tracking, output tracking, predictive control with integrator and time-varying reference tracking. Explicit model predictive control.

**Robust Control (2h/week, 4th semester)** Introduction to the robust control and one-parametric uncertainties. Interval uncertainties, robust stability analysis of systems with interval uncertainties and Kharitonov Theorem. Synthesis of robust controllers for systems with interval uncertainties. Polytopic uncertainties, edges, analysis of robust stability for the polytopic systems and Edge Theorem. Multi-linear parametric uncertainties. Design of robust control for the systems with parametric uncertainties, simultaneous stabilization. Low gain theory, generalized Kharitonov Theorem.

Introduction to the LMI systems and robust controllers design using LMIs. Unstructured uncertainties and analysis of robust stability. Analysis methods of the robust stability for systems with unstructured uncertainty and analysis methods of the robust stability for system with unstructured uncertainties.

### 5.4.4 Laboratory Exercises in Master Study

**Information Technology I (2h/week, 1st semester)** Computer terminology. Basic hardware and software. Network protocols and architectures. Data security and protection. Design of static web pages. Basic structure of a web page. XHTML language – elementary tags and attributes. Cascade style sheet formatting.

**Information Technology II (2h/week, 3st semester)** Students have knowledge of making static and dynamic websites. They are able to create simple web pages. They know fundamentals of HTML, CSS, PHP and SQL.

**Creation of Scientific Documents (2h/week, 3rd semester)** Student has knowledge how to create scientific documents with both WYSIWYG and transformation methods. He/she is able to work with bibliographic information, correctly cite various sources. Students can work with typesetting tool LaTeX, can generate in batch different presentation and print outputs.

He/she also has knowledge about structured text systems as XML or DocBook.

**Project Software Systems (2h/week, 3rd semester)** The course is divided into four main parts. The first one introduces students to basic concepts of version control systems (VCS) and explains differences between the centralized approach and the distributed one. The second part explains the usage of the Mercurial distributed VCS and shows how to operate it from the command line. The third part discusses the GIT distributed VCS. The final part is devoted to graphical user interfaces for VCS adn web-based collaboration platforms.

**Process Control Project (3h/week, 3rd semester)** Project represents individual student work to solve control of laboratory processes in chemical and biochemical technologies. Student has to combine knowledge from various subjects in engineering study. He studies a selected laboratory process, designs and simulates its behaviour and verifies at the actual plant. In conclusions, forms results and presents them.

# 6 Current Research Activities

Research at the Department of Process Control is oriented to advanced control theory as so as to practical applications in control of processes of chemical technology.

## 6.1 Main Research Areas

**Modeling and Simulation (M. Bakošová, J. Mikleš)** Modeling and simulation play an important role in the investigation of static and dynamic properties of chemical processes, units and systems. Most chemical systems are strongly non-linear and their simulation is necessary for the control design as well as for the investigation of the overall control systems. The main aim of the research is to develop program packages for modeling and simulation of various kinds of models. During the last year a package MODELTOOL for MATLAB/ Simulink was improved and its Internet module was created.

**System Identification (Ľ. Čirka, M. Fikar, J. Mikleš, J. Števek)** System identification deals with problem of the parameter estimation of static or dynamic systems from observed input-output data. Among many topics of system identification, the following areas have been investigated in this project:

- nonparametric methods, correlation and spectral analysis
- recursive identification of transfer functions of continuous-time systems, Z-transform discrete-time models and delta-transform discrete-time models
- identification in closed-loop

A program package IDTOOL has been developed for Simulink. This toolbox implements recursive LS algorithm LDDIF and provides blocks for continuous and discrete time parameter estimation.

**Optimal Control Design (M. Fikar, J. Mikleš, M. Jelemenský)** The main aim of this area is to develop a package of algorithms and program implementation of various known control design for a given plant. The research interests include single input-single output systems as well as multi-variable dynamic systems. Control design covers strategies in discrete-time and continuous-time formulation. A program package is created in MATLAB and Simulink environment.

**Adaptive Control (M. Bakošová, Ľ. Čirka, M. Fikar, A. Mészáros, J. Mikleš)** Most of technological plants exhibit non-linear behavior. To apply a successful control design to practical problems is a substantial effort. The processes are known to be modeled and controlled with serious difficulties caused by their non-linear behavior, high order dynamics, and tendency to instability. Many of industrial processes must be considered as multi-variable systems. In a great deal of available control design techniques it is often necessary to carry out the steps of modeling, identification and control design. Theory and implementation of adaptive control in technological systems have been the long-time research topics. The activities in the adaptive control have been concentrated to three main areas as follows:

- self-tuning control – characterized by repeating parameter estimation and control design
- model reference adaptive control based on the Lyapunov method
- decentralized adaptive control

**Neural Networks and Fuzzy Control (A. Mészáros, A. Vasičkaninová)** The aim of this research is to investigate fuzzy controllers based on genetic algorithms, two-layer hierarchical control structures for biochemical systems, integrated optimizing algorithms for higher layers of hierarchical control structures, artificial neural-network models obtained by back-propagation for specified biochemical systems, design of a robust long-range constrained predictive control algorithms on the basis of ANN involving a stochastic approximation training algorithm, and development of a control system for our laboratory fermenter.

**Model Predictive Control (M. Fikar, M. Kvasnica, M. Klaučo, J. Holaza, B. Takács, J. Drgoňa, D. Ingole, J. Števek)** Model Predictive control (MPC) has been successful not only in academia but in industrial process applications as well. Its main drawbacks are the stability problems. The aim of this research is to enhance the basic input-output predictive methods. The problem is solved by means of the Youla-Kučera parametrization of all stabilizing controllers. Both finite and infinite horizon formulations are handled. Another approach is to assume that the loop is already controlled by a linear controller and to find the minimum number of control, or tracking error steps that leads to stable closed-loop behavior. In all cases, it can be shown that the minimum number of steps is closely related to the number of unstable poles/zeros of the plant. Another area of research is development of new methods for explicit model predictive control. In this approach, the optimal solution to the given MPC problem is obtained for all admissible initial conditions by employing parametric programming methods. The resulting optimal feedback law is then represented by a look-up table, which allows for real-time implementation of MPC to processes with rapid sampling.

**Dynamic Optimisation (M. Fikar, D. Pakšiová, R. Paulen, J. Jelemenský, A. Sharma)** Increased quality requirements in chemical and petrochemical industries call for more complicated and sophisticated control strategies. Moreover, there is a need to know the achievable limits of performance and speed of transient behavior of processes. Optimal control theory is able to provide responses to these questions. In this research, changeover problems in multicomponent distillation, waste-water treatment are studied.

**Modelling and Control of Chemical Reactors, Biochemical Reactors, Distillation Columns and Heat Exchangers (M. Bakošová, Ľ. Čirka, M. Fikar, A. Mészáros, J. Mikleš, A. Vasičkaninová)** The research of all research groups is focused on modelling and control of various types of chemical and biochemical processes.

**Robust Control (M. Bakošová, J. Oravec, A. Vasičkaninová)** Research is focused to design the robust control and robust model predictive control of the system in the presence of the uncertain parameters. The investigated systems are the processes of the chemical and food technology, such as chemical reactors, heat exchangers and the others. From the control viewpoint the main demands are the stability issues, control performance, the optimization of energy resources, and a overall computational burden. The designed robust control is validated using the simulation of control and the real laboratory processes.

**Control Engineering Education (M. Fikar, Ľ. Čirka, M. Bakošová, M. Kalúz, J. Oravec, R. Valo)** Research in this domain focuses on application of information technologies in control education. This covers interactive on-line blocks and automatic generation of testing problems. The current research involves personification of students problems.

**Information Technologies (M. Fikar, Ľ. Čirka, M. Kvasnica, M. Kalúz)**
Research in this domain is oriented to:

- application of information technologies for data treatment and visualisation
- development of static and dynamic web pages not only for purposes of measurement and control but for general information treatment
- automatic data acquisition from various internet sources

Open Source solutions are applied: web, mail, smb servers, databases (MySQL), programming tools (PHP, JavaScript) on operating systems FreeBSD, GNU Linux, Solaris.

## 6.2 Research Projects in Slovak Republic

### 6.2.1 VEGA 1/0403/15: Verifiably Safe Optimal Control (M. Kvasnica)

Period: 2015 – 2018

This research project is devoted to design, synthesis, and implementation of optimal control systems for process control applications which require rigorous guarantees that the control system will exhibit desired safety and economical properties. The parameters of safety and economical behavior are divided into theoretical properties (closed-loop stability, recursive feasibility and satisfaction of process constraints), and practical properties (guaranteed execution of the optimization algorithm on platforms with restricted computational resources, correct behavior of the control system under quantization and under failures of the communication channels). Nowadays, these properties are verified by extensive testing, which is time consuming and expensive. Therefore the main goal of the project is to develop a unified methodology which allows to design optimal control systems in which safety properties can be imposed and verified already at the design stage.

### 6.2.2 VEGA 1/0973/12: Control of Processes with Uncertainties in Chemical Technology and Biotechnology (M. Bakošová)

Period: 2012 – 2015

The scientific project deals with development of advanced control methods for systems with uncertainties and focuses on processes typical in chemical and food technologies, as e.g. chemical reactors, biochemical reactors, distillation columns, heat exchangers and other energy consuming processes. Development of methods of robust stabilization and robust predictive control of systems with uncertainties constitutes the core of the project and the goal is to assure more efficient energy saving control in comparison to classical approaches. Computational requirements and practical use will be taken into account in the design of control algorithms. Designed algorithms, controllers, and control structures will be tested by simulations and in laboratory conditions. They will be compared with classical ones from the viewpoint of energy consumption during the control.

### 6.2.3 VEGA 1/0053/13: Optimal Process Control (M. Fikar)

Period: 2013 – 2016

The main project aim is design of optimal operation of selected processes in chemical and food technologies. It will primarily focus on two process types: membrane filtration processes and polymerization reactors. For membrane processes, we will concentrate on fouling effects and on embedded membrane processes as a part of the overall technology. For polymerization reactors, we will study hybrid behaviour corresponding to different stages during polymer production and we will propose effective control structures.

Theoretic results will be sought in study of global deterministic methods that are able to find not only a local solution but converge to a neighbourhood of the global solution in a finite time. The aim is to design such methods and algorithms that will be usable for optimization of more detailed process models and for estimation of their parameters.

The obtained results will be implemented in open source software packages and available in Internet. The aim is a broader dissemination of results in optimal control and optimal parameter estimation in process technologies.

### 6.2.4 APVV-0551-11: Advanced and Effective Methods of Optimal Process Control (M. Fikar)

Period: 2012 – 2015

The project is focused on research and development of optimal control methods of nonlinear systems. Such systems are typical in chemical and biochemical technologies as separations, chemical reactors, waste-water treatment plants. The project will deal with design of advanced methods and control algorithms that will be more effective than the actual ones with respect to memory consumption and computational power. This will make possible to implement easier newly developed methods in industrial control systems. On the top layer, dynamic optimization will be used for qualitative analysis and as a generator of optimal trajectories. The suboptimal bottom layer represented by MPC and robust controllers will approximate the desired optimal operation and we will study the degree of suboptimality of these approaches. Other goals include providing a user-friendly software implementation of such a two-tiered architecture accessible to typical control engineers, as well as validation of the proposed solutions on experimental devices.

### 6.2.5 Development of Laboratory Traffic Simulator (M. Kalúz)

Internal Grant of the Slovak University of Technology in Bratislava

Period: 2015 – 2016

Abstract: The project is aimed on a development of laboratory robotic simulator that allows an effective control applications for various traffic scenarios. These involve the traffic jams, cruise control, cross-sections and junctions of paths, collision avoidance and other. Laboratory simulator will include robotic vehicles equipped with a set of sensors for the spacial orientation and awareness of other traffic participants. Each robot will be equipped with the separate control unit that will allow its autonomous and centralized control. The project considers the usage of ten such robotic vehicles, which will allow the evaluation of different spacial traffic deployments on the road infrastructure. For the needs of centralized vehicle control, a computer vision system is considered to be developed as well in this project. One of the main areas of this project will be the applications of model predictive control for optimal traffic congestion flow. This approach has a significant potential for the improvement of traffic fluency, reduction of vehicle operation costs, as well as the reduction of gas emissions.

### 6.2.6 Predictive Control of Processes with Fast Dynamics (D. Ingole)

Internal Grant of the Slovak University of Technology in Bratislava

Period: 2015 – 2016

The goal of this project is to obtain lowcost laboratory experiments for an application of fast model predictive control. It is a challenge to apply advanced control techniques to processes with high number of control inputs and short operating cycle (milisecods).

This project targets a development and application of control algorithms that were developed within VEGA project no. 1/0095/11. The purpose of the project is to create a methodology for imeplementing fast control algorithms for various programming platforms (matlab, python, c++, java, lisp)

### 6.2.7 Safe Optimal Control of Technological Processes (J. Oravec)

Internal Grant of the Slovak University of Technology in Bratislava

Period: 2015 – 2016

The project is aimed to extend the posibilities of safe optimal control design for a wide class of technological processes. The project implements the advanced optimization techniques to design the safe and economically effective control algorithm. The quality of the control performance is evaluated subject to the safety crietria, input costs, and energy demands. The unnegliable quality criterion is also the overall computational effort that is minimized. Particular goals of the project are the software tools freely avaiable by Inernet.

**Objectives**: Main objectives of the project involve solving these particular tasks:

- conservativeness reduction of safe and robust model predictive control (MPC),
- design of the advanced safe and robust MPC of uncertain multiple-input and multiple-output systems subject to input and output constraints,
- safe and optimal control design using the analytical and numerical solution of dynamic optimization,
- implementation of safe and optimal control designed by the means of explicit MPC using the hardware of limited memory and CPU,

- development fo the software tool for generation of advanced safe optimal control algorithm,
- further development of the software package for modeling and robust MPC of the processes of chemical and food technologies,
- implementation and validation of the designed approaches using the simulatio of control and control of the real processes.

### 6.2.8 Design of Optimal Control for Membrane Separation Processes (M. Jelemenský)

Internal Grant of the Slovak University of Technology in Bratislava

Period: April 2015 – December 2015

The main objective of the project is to design optimal control for membrane separation processes in the presence of membrane fouling. Optimal control of the final product will ensure a certain quality in the shortest possible time. Mathematically, the optimization problem is very complex and strongly non-linear, and thus to obtain optimal control requires great computing power. However, the big advantage is that the solution (e.g. optimal control) which is obtained, can be easily applied to available devices that have limited processing power but are commonly used in the chemical and food industry.

### 6.2.9 Automatic Code Generation for Implementation of Model Predictive Control (B. Takács)

Internal Grant of the Slovak University of Technology in Bratislava

Period: April 2015 – December 2015

This project is focused on software development tool for automatic generation algorithm as a solution to an optimization problem, which can take the form Linear Programming (LP), Quadratic Programming (QP) or Mixed Integer Programming (MIP). Nowadays there exists numerous applications which uses optimization in order to reduce the cost of production, transport and storage, while in the other hand the goal is to increase the revenue. The mentioned forms of the optimization tasks are also used in the formulation and subsequent solution of so-called model predictive control. The formulation of the final optimization problem is based on the information on the mathematical models of real devices. The generated algorithm requires only information about the actual states of the controlled system. Based on this information it returns the control action, which minimizes the given index of quality (usually the amount of energy). Such control is widely used from the chemical to automotive industry. The research project focuses on the generation of effective algorithms to various popular programming languages, thus ensuring easy implementation of control algorithms and modularity.

## 6.3 Other Projects in Slovak Republic

### 6.3.1 University Scientific Park STU Bratislava

Period: 2013 – 2015

Project aims:

- To strengthen cooperation in research and development between industrial and academic spheres by creating of university research part oriented to selected research fields
- To create and develop university research park STU Bratislava Applied research
- To support transfer of technologies and knowledge to praxis

### 6.3.2 Slovkord s.r.o in Senica

Period: 11/2014 – 01/2015

- Analysis of data measured in PET production
- Statistical analysis

## 6.4 International Scientific Projects

### 6.4.1 Training in Embedded Predictive Control and Optimization (M. Fikar, M. Kvasnica)

Period: 2014–2018

Financing: European Commission – Framework Program 7, MC ITN

TEMPO is an international PhD program for highly motivated young scientists, where state-of-the-art research is combined with a comprehensive training program. The network is funded by the European Community's Seventh Framework program. TEMPO addresses the needs of European companies and society for embedded control technology, through training on cutting edge research in the rapidly emerging inter-disciplinary field of embedded predictive control and optimization.

Ten partners from academia and industry, as well as three associated partners will provide a multi-national and interdisciplinary training infrastructure, designed to equip the participating fellows with the necessary knowledge and set of tools to pursue successful careers.

Project main page: http://www.itk.ntnu.no/tempo/

### 6.4.2 APVV SK-FR-2013-0026

**Complexity, Sensitivity and Robustness in Explicit Model Predictive Control**

Period: 2014 – 2015

Partners:

- Slovak University of Technology in Bratislava (M. Kvasnica, J. Drgoňa, J. Holaza, B. Takács)
- Ecole Superieur d'Electricite (SUPELEC) (P. Rodriguez-Ayerbe, S. Olaru, C. Vlad, A. Nguyen, T.M. Nguyen)

The proposed project is dedicated to the topic of model predictive control with a specific emphasis in their explicit solutions. The main goal is to develop new techniques for designing such control law with low complexity in view of deployment for fast real-time applications. In this project the scientific objective is to address complexity reduction in the explicit control laws, to analyse sensitivity of the optimal solutions and their implications to the robustness/fragility, and to apply developed algorithms in applications (power converters, or other appropriate benchmarks).

# 7 Cooperations

## 7.1 Cooperations in Slovakia

- Institute of Robotics and Cybernetics, Faculty of Electrical Engineering and Informatics, Slovak University of Technology in Bratislava
- Institute of Automation, Measurement, and Applied Informatics, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava
- Institute of Automotive Mechatronics, Faculty of Electrical Engineering and Informatics, Slovak University of Technology in Bratislava
- Institute of Informatics, Slovak Academy of Sciences, Bratislava
- Department of Cybernetics and Artificial Intelligence, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Košice
- Faculty of Mining, Ecology, Process Control and Geotechnology, Technical University of Košice, Košice
- ProCS s.r.o, Actemium Slovakia, Šaľa
- Slovnaft, Inc., Bratislava
- Schneider Electric (Slovakia) s.r.o., Bratislava
- Regotrans-Rittmeyer Slovakia s.r.o., Bratislava

## 7.2 International Cooperations

- Department of Process Control and Computer Techniques, Faculty of Chemical Technology, University of Pardubice, Pardubice, Czech Republic (Control system design)
- Department of Computing and Control Engineering, Prague Institute of Chemical Technology, Prague, Czech Republic (Control system design)
- Faculty of Applied Informatics, Tomas Bata University, Zlín, Czech Republic (Adaptive control, robust control)

- Institute of Information Theory and Automation of the Academy of Sciences of the Czech Republic, Prague, Czech Republic (Polynomial synthesis, Model Predictive Control)
- Faculty of Electrical Engineering, Czech Technical University, Prague, Czech Republic (Model Predictive Control)
- LSGP-CNRS, Ecole Nationale Superieure des Industries Chimiques (ENSIC), Nancy, France (Dynamic optimisation and control)
- CentraleSupélec, Paris, France (MPC)
- Automatic Control Laboratory, ETH Zurich, Switzerland (Model Predictive Control, Modeling, analysis, and control of hybrid systems)
- University of Dortmund, Dortmund, Germany (Model Predictive Control)
- Technical University of Budapest, Budapest, Hungary (Modelling of chemical processes)
- Corvinus University of Budapest, Budapest, Hungary (Membrane Engineering)
- University of Veszprem, Hungary (Environmental engineering, Bioengineering projects)
- Centre for Process Systems Engineering, Department of Chemical Engineering, Imperial College London, United Kingdom (Global optimization, Parameter estimation)
- NTNU Trondheim, Norway (Process Control, MPC)
- DeustoTech, Faculty of Engineering, University of Deusto, Bilbao, Spain (Control education, Remote laboratories)

## 7.3 Membership in Domestic Organizations and Societies

- Slovak Society for Cybernetics and Informatics (M. Fikar, A. Mészáros, J. Mikleš)
- Slovak Society of Chemical Engineering (M. Bakošová, M. Fikar, A. Mészáros, J. Mikleš)
- Slovak Society of Industrial Chemistry (M. Bakošová, Ľ. Čirka, M. Fikar, A. Mészáros, J. Mikleš, A. Vasičkaninová)

## 7.4 Membership in International Organizations and Societies

- International Federation of Automatic Control, Laxenburg, Austria (M. Fikar)
- European Federation of Biotechnology, Brussels, Belgium (A. Mészáros)
- New York Academy of Sciences, New York, USA (A. Mészáros)
- European Union Control Association (M. Kvasnica)
- European Membrane Society (R. Paulen)
- IEEE (M. Fikar, M. Kalúz, M. Kvasnica)

# 8 Theses and Dissertations

## 8.1 Bachelor Theses (BSc. degree)

for state examinations after three years of study (supervisors are written in parentheses)

| | |
|---|---|
| Bakaráč, P. | Optimal Control of Fresnel Lens<br>(Kvasnica, M.) |
| Batárová, K. | Modern Diagnostic Methods in Medicine (Physicochemical Aspects)<br>(Oľga Holá) |
| Chochoľák, F. | Optimization of Transportation and Logistic Systems<br>(Kvasnica, M.) |
| Hodúrová, B. | MOODLE-Based Teaching Materials for the Optimization Course<br>(Kvasnica, M.) |
| Jakabšic, J. | Implementation of Optimization Algorithms in Javascript<br>(Kvasnica, M.) |
| Karško, J. | Models of Data Files<br>(Varga, Š.) |
| Kirová, K. | Creation of a Library of Models of Technological Processes<br>(Čirka, Ľ.) |
| Kollárová, M. | Optimization-based Approach to Reduction of Traffic Jams<br>(Kvasnica, M.) |
| Koniar, S. | Model Predictive Control of Rectification Column<br>(Kvasnica, M.) |
| Kostka, M. | Module for Storing Proccess Data from Remote Laboratories<br>(Kalúz, M.) |
| Mikušová, N. | Data Classification Based on Support Vector Machine<br>(Kvasnica, M.) |
| Mišenko, M. | Design of Fuzzy and Neuro - Fuzzy Controllers<br>(Vasičkaninová, A.) |

| | |
|---|---|
| Nitrianska, V. | Design of Quizzes in LMS Moodle<br>(Vasičkaninová, A.) |
| Panghyová, L. | Laboratory Heat Exchanger LTR 700 in terms of Industrial Control<br>(Valo, R.) |
| Prokeinová, K. | Identification and Controller Synthesis for a Laboratory Heat Exchanger<br>(Oravec, J.) |
| Šimek, M. | Creation of Website ŠVK in the Content Management System Drupal<br>(Čirka, Ľ.) |

## 8.2 Master Theses (MSc. degree)

for state examinations after five years of study (supervisors are written in parentheses)

| | |
|---|---|
| Janočko, D. | Remote Laboratories for Fast-Dynamic Systems<br>(Kalúz, M.) |
| Kukla, V. | Laboratory Experiment DTS200: Three Tank System in the Automatic Control Perspective<br>(Valo, R.) |
| Minárik, J. | Quantum-Chemical Computing on GPU<br>(Gall, M.) |
| Pakšiová, D. | Optimal Control of Processes in Chemical Technology<br>(Fikar, M.) |
| Virguľa, P. | Robust Control<br>(Vasičkaninová, A.) |

# 9 Publications

## 9.1 Chapters or Pages in Books

1. Vasičkaninová, A. – Bakošová, M. – Oravec, J.: *Use of artificial intelligence in the modeling and control of chemical processes (in Slovak)*, In *Chémia – neoddeliteľná súčasť prírodných vied*, Editor(s): Ondrejkovičová I., Izakovič M., Slovenská chemická knižnica FChPT STU v Bratislave, vol. 1, pp. 126–142, 2015.

## 9.2 Articles in Journals

1. Cseko, L. – Kvasnica, M. – Lantos, B.: Explicit MPC-Based RBF Neural Network Controller Design With Discrete-Time Actual Kalman Filter for Semiactive Suspension. **IEEE Transactions on Control Systems Technology**, no. 5, vol. 23, pp. 1736–1753, 2015.

2. Herceg, M. – Jones, C. – Kvasnica, M. – Morari, M.: Enumeration-based approach to solving parametric linear complementarity problems. **Automatica**, no. 62, pp. 243–248, 2015.

3. Holaza, J. – Takács, B. – Kvasnica, M. – Di Cairano, S.: Nearly optimal simple explicit MPC controllers with stability and feasibility guarantees. **Optimal Control Applications and Methods**, no. 6, vol. 35, 2015.

4. Honek, M. – Kvasnica, M. – Szűcs, A. – Šimončič, P. – Fikar, M. – Rohaľ-Ilkiv, B.: A low-complexity explicit MPC controller for AFR control. **Control Engineering Practice**, no. 42, pp. 118–127, 2015.

5. Jelemenský, M. – Paulen, R. – Fikar, M. – Kovacs, Z.: Time-Optimal Operation of Multi-Component Batch Diafiltration. **Computers & Chemical Engineering**, vol. 83, pp. 131–138, 2015.

6. Kalúz, M. – García-Zubía, J. – Fikar, M. – Čirka, Ľ.: A Flexible and Configurable Architecture for Automatic Control Remote Laboratories. **IEEE Transactions on Learning Technologies**, 2015.

7. Martí, R. – Lucia, S. – Sarabia, D. – Paulen, R. – Engell, S. – de Prada, C.: Improving scenario decomposition algorithms for robust nonlinear model predictive control. **Computers & Chemical Engineering**, vol. 79, pp. 30–45, 2015.

8. Mészáros, A. – Čirka, Ľ. – Bakošová, M. – Vasičkaninová, A.: On Stability and Controllability of Processes with Internal Recycle. **Professor Dr Jiří Klemeš: Celebration of the Jubilee in Science and Engineering, Chemical Engineering Transactions**, no. 45, pp. 1735–1740, 2015.

9. Oravec, J. – Bakošová, M.: Robust Model-Based Predictive Control of Exothermic Chemical Reactor. **Chemical Papers**, no. 7, vol. 69, 2015.

10. Oravec, J. – Bakošová, M. – Mészáros, A.: Comparison of Robust Model-based Control Strategies Used for a Heat Exchanger Network. **Chemical Engineering Transactions**, no. 45, pp. 397–402, 2015.

11. Paulen, R. – Jelemenský, M. – Kovacs, Z. – Fikar, M.: Economically optimal batch diafiltration via analytical multi-objective optimal control. **Journal of Process Control**, vol. 28, pp. 73–82, 2015.

12. Sharma, A. – Fikar, M. – Bakošová, M.: Comparative study of Time Optimal Controller with PID Controller for a Continuous Stirred Tank Reactor. **Acta Chimica Slovaca**, no. 1, vol. 8, pp. 27–33, 2015.

13. Špánik, I. – Čirka, Ľ. – Májek, P.: Classification of wine distillates using multivariate statistical methods based on their direct GC-MS analysis. **Chemical Papers**, no. 3, vol. 69, pp. 395–401, 2015.

14. Vasičkaninová, A. – Bakošová, M.: Control of a heat exchanger using neural network predictive controller combined with auxiliary fuzzy controller. **Applied Thermal Engineering**, no. 89, pp. 1046–1053, 2015.

15. Vasičkaninová, A. – Bakošová, M.: Fuzzy Model-based Neural Network Predictive Control of a Heat Exchanger. **Chemical Engineering Transactions**, no. 45, pp. 313–318, 2015.

## 9.3 Articles in Conference Proceedings

1. Chachuat, B. – Houska, B. – Paulen, R. – Peric, N. – Rajyaguru, J. – Villanueva, M.: Set-Theoretic Approaches in Analysis, Estimation and Control of Nonlinear Systems. In *9th International Symposium on Advanced Control of Chemical Processes ADCHEM 2015 Whistler, British Colombia, Canada, 7-10 June 2015*, pp. 982–996, 2015.

2. Drgoňa, J. – Klaučo, M. – Valo, R. – Bendžala, J. – Fikar, M.: Model Identification and Predictive Control of a Laboratory Binary Distillation Column. Editor(s): M. Fikar and M. Kvasnica, In *Proceedings of the 20th International Conference on Process Control*, Slovak Chemical Library, Štrbské Pleso, Slovakia, 2015.

3. Drgoňa, J. – Klaučo, M. – Kvasnica, M.: MPC-Based Reference Governors for Thermostatically Controlled Residential Buildings. Editor(s): Astolfi, A, In the *54th IEEE Conference on Decision and Control*, Osaka, Japan, 2015.

4. Holaza, J. – Takács, B. – Kvasnica, M. – Di Cairano, S.: Safety Verification of Implicitly Defined MPC Feedback Laws. In *European Control Conference 2015*, Linz, Austria, pp. 2552–2557, 2015.

5. Ingole, D. – Holaza, J. – Takács, B. – Kvasnica, M.: FPGA-Based Explicit Model Predictive Control for Closed-Loop Control of Intravenous Anesthesia. Editor(s): M. Fikar and M. Kvasnica, In *Proceedings of the 20th International Conference on Process Control*, Slovak Chemical Library, Štrbské Pleso, Slovakia, pp. 42–47, 2015.

6. Ingole, D. – Kvasnica, M.: FPGA Implementation of Explicit Model Predictive Control for Closed Loop Control of Depth of Anesthesia. In *Preprints of the 5th IFAC Conference on Nonlinear Model Predictive Control*, pp. 484–489, 2015.

7. Jelemenský, M. – Sharma, A. – Paulen, R. – Fikar, M.: Time-optimal Operation of Diafiltration Processes in the Presence of Fouling. Editor(s): Krist V. Gernaey and Jakob K. Huusom and Rafiqul Gani, In *12th International Symposium on Process Systems Engineering And 25th European Symposium on Computer Aided Process Engineering*, Elsevier B.V, Copenhagen, Denmark, pp. 1577–1582, 2015.

8. Jelemenský, M. – Sharma, A. – Paulen, R. – Fikar, M.: Multi-Objective Optimization of Batch Dialfiltration Processes in the Presence of Membrane Fouling. Editor(s): M. Fikar and M. Kvasnica, In *Proceedings of the 20th International Conference on Process Control*, Slovak Chemical Library, Štrbské Pleso, Slovakia, pp. 84–89, 2015.

9. Kalúz, M. – Klaučo, M. – Kvasnica, M.: Real-Time Implementation of a Reference Governor on the Arduino Microcontroller. Editor(s): M. Fikar and M. Kvasnica, In *Proceedings of the 20th International*

*Conference on Process Control*, Slovak Chemical Library, Štrbské Pleso, Slovakia, pp. 350–356, 2015.

10. Nehéz, M. – Bernát, D. – Klaučo, M.: Comparison of Algorithms for Near-Optimal Dominating Sets Computation in Real-World Networks. Editor(s):B. Rachev, A. Smrikarov, In *Proceedings of the 16th International Conference on Computer Systems and Technologies*, Association for Computing Machinery (ACM), Dublin, Ireland, pp. 199–206, 2015.

11. Kvasnica, M. – Holaza, J. – Takács, B. – Ingole, D.: Design and Verification of Low-Complexity Explicit MPC Controllers in MPT3. In *European Control Conference 2015*, Linz, Austria, pp. 2600–2605, 2015.

12. Kvasnica, M. – Takács, B. – Holaza, J. – Ingole, D.: Reachability Analysis and Control Synthesis for Uncertain Linear Systems in MPT. Editor(s): Fikar, M., In *Proceedings of the 8th IFAC Symposium on Robust Control Design*, Elsevier, Bratislava, Slovak Republic, no. 8, pp. 302–307, 2015.

13. Kvasnica, M. – Takács, B. – Holaza, J. – Di Cairano, S.: On Region-Free Explicit Model Predictive Control. Editor(s): Astolfi, A, In the *54th IEEE Conference on Decision and Control*, Osaka, Japan, 2015.

14. Martí, R. – Lucia, S. – Sarabia, D. – Paulen, R. – Engell, S. – de Prada, C.: An Efficient Distributed Algorithm for Multi-Stage Robust Nonlinear Predictive Control. In *European Control Conference 2015*, Linz, Austria, pp. 2669–2674, 2015.

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