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IN BRATISLAVA

FACULTY OF CHEMICAL AND FOOD  
TECHNOLOGY

INSTITUTE OF INFORMATION ENGINEERING, AUTOMATION,  
AND MATHEMATICS

DEPARTMENT OF INFORMATION  
ENGINEERING AND PROCESS CONTROL



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# 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. It educates high-qualified specialists in the field of process control for design, implementation, and application of control systems. The educational pyramide includes 3 year bachelor study (program Information Engineering, Automation and Management in Chemical and Food Industry), 2 year master study (program Information Engineering and Automation in Chemical and Food Industry) and 4 year PhD study (program Process Control).

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, 2016.

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 2000 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.

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## 4 Teaching and Research Laboratories

### Laboratory of Process Control:

- Distillation Column Armfield UOP3CC
- Membrane Process SUPER RO BM 30
- 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, Oravec
Fundamentals of Matlab	0/0/2	Janeček, Oravec

#### 2nd semester (Summer)

Fundamentals of Electrotechnics	0/2/0	Valo
Information Engineering and Information Systems	1/0/2	Čírka, Kalúz
MATLAB – Advanced Techniques	1/0/1	Števek
Spreadsheet and Database Systems for Data Processing	0/0/2	Čírka

#### 3rd semester (Winter)

Fundamentals of Language C	0/0/2	Holaza, Kvasnica
Fundamentals of Matlab	0/0/2	Čírka, Vasičkaninová
Linux – Basic Automation	0/0/2	Valo
Modelling	2/0/3	Mészáros, Vasičkaninová
Operating Systems	0/0/2	Valo
Programming of Web Applications	1/0/2	Čírka

#### 4th semester (Summer)

Fundamentals of Embedded System Control	0/0/2	Kalúz
Internet and Information Systems	0/0/2	Čírka
Laboratory of Process Control	0/0/2	Oravec, Sharma
Programming I	2/0/2	Drgoňa, Kvasnica

Spreadsheet and Database Systems for Data Processing	0/0/2	Čírka
Web Technologies in Automation	0/0/2	Čírka
<b>5th semester (Winter)</b>		
Design of Information and Control Systems	2/0/3	Kvasnica, Valo
Introduction to XML Technologies	1/0/1	Holaza, Kvasnica
Optimization	2/0/2	Klaučo, Kvasnica, Pakšiová
<b>6th semester (Summer)</b>		
Integrated Control in Process Industries	2/0/3	Bakošová, Vasičkaninová
Laboratory of Process Control	0/0/2	Jelemenský, Kalúz, Oravec, Števek, Vasičkaninová
Process Control	2/0/0	Bakošová
Programming II	1/0/2	Drgoňa, Kvasnica
Web Technologies in Automation	0/0/2	Čírka

## 5.2 Master Study

<b>1st semester (Winter)</b>		
Automatic Control Theory I	2/0/3	Fikar, Klaučo
Information Technology I	0/0/2	Čírka
Modelling in Process Industry	2/2/0	Bakošová, Oravec, Vasičkaninová
Process Dynamics and Control	2/0/1	Bakošová, Vasičkaninová
Programming of Web Applications	1/0/2	Čírka
Technical Means of Automation	2/0/2	Kalúz



**2nd semester (Summer)**

Automatic Control Theory II	2/0/3	Fikar, Pakšiová
Identification	2/0/2	Čirka, Fikar
Information Engineering and Industrial Information Systems I	1/0/3	Kvasnica, Valo
Informatization, Digitalization and Documentation of Heritage	1/2/0	Kvasnica
Modelling in Process Industry	2/2/0	Bakošová, Oravec, Vasičkaninová

**3rd semester (Winter)**

Automatic Control Theory III	2/0/2	Fikar, Oravec
Information Engineering and Industrial Information Systems II	2/0/2	Kvasnica, Sharma
Information Technologies II	0/0/2	Čirka
Network Fundamentals	0/0/2	Fikar
Optimisation of Processes and Plants	2/0/2	Klaučo, Kvasnica
Process Control Project	0/0/3	Kalúz
Project Software Systems	0/2/0	Janeček

**4th semester (Summer)**

Diploma Project	0/0/20	Čirka
Intelligent Control	1/2/0	Mészáros
Predictive Control	1/2/0	Fikar, Ingole, Kvasnica
Robust Control	1/2/0	Bakošová, Oravec

## 5.3 PhD Study

### 1st year

Modeling and Control of Biotechnological Processes	2/0/3	Bakošová
Modeling and Control of Chemical Processes	2/0/3	Bakošová
Optimal Control	2/0/3	Fikar
Advanced Predictive Control	2/3/0	Kvasnica
Selected Topics in Intelligent Control	2/0/3	Fikar
Selected Topics in the Theory of Automatic Control	2/0/3	Fikar

## 5.4 Course Contents

### 5.4.1 Lectures in Bachelor Study

#### **Information and Information Systems (1h/week, 2<sup>nd</sup> and 6<sup>th</sup> semester)**

Static and dynamic pages, web technologies – HTML and XHTML, creation of html documents. HTML: structure of HTML document (head, body). HTML: text, links, ordered and unordered lists. HTML: graphics, tables. HTML: forms (methods, form elements, attributes), evaluation of form data. HTML: frames, applets, servlets CSS: introduction to formatting using cascade styles. CSS: colour, font, alignment, links. CSS: ordered and unordered lists, borders, background. CSS: classes and identifiers. Practical webdesign: planning, design (effective navigation, colours, text, graphics, animations), publishing, maintenance. Google - search, Gmail, YouTube, Picasa, Blogger, Talk, Earth, Maps. Google - Images, Video, Book Search, Calendar, Documents, Notebook.

#### **MATLAB – Advanced Techniques (1h/week, 2<sup>nd</sup> semester)**

Introduction to MATLAB. Basic architecture of MATLAB. Functions I. Functions II. Functions III. Functions for working with data. Symbolic toolbox. Introduction to Object-Oriented Programming. Graphics objects. GUIDE – graphical user interface. Low-level input and output. HTTP MATLAB Web Server I. HTTP MATLAB Web Server II.

**Modeling (2h/week, 3<sup>rd</sup> semester)** Introduction to process modeling, approaches to modeling, types of mathematical models. Static and dynamic mathematical models of basic types of processes in chemical and food technology: tanks, mixers, various types of heat exchangers, continuous stirred tank reactors. Simulation of the static and dynamic behaviour of selected processes in chemical and food technology using the simulation software MATLAB - Simulink.

**Process Control (2h/week, 4<sup>th</sup> and 6<sup>th</sup> semester)** Laplace transform. Transfer function and transfer functions of complex systems. Step response. Impulse response. Poles and zeros. Modelling of tanks. Modelling of heat exchangers. Modelling of a chemical reactor. On-off controller. PID controller. Feed-back control loop. Stability. Reference tracking and disturbance rejection. Control performance. Analytical methods for controller synthesis. Experimental methods for controller synthesis. Measurement of process variables. Technological schemes with measurement and control loops.

**Programming I (2h/week, 4<sup>th</sup> 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.

**Optimization (2h/week, 5<sup>th</sup> 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.

**Design of Information and Control Systems (2h/week, 5<sup>th</sup> semester)** The course is divided into two major parts. The first one covers synthesis of simple controllers based on logic rules, their representation using finite state machines, as well as their implementation in Stateflow. The second part is

devoted to implementation of logic control on Programmable Logic Controllers using Ladder logic.

**Introduction to XML Technologies (1h/week, 5<sup>th</sup> semester)** The course is divided into two parts. The first one covers structure of XML documents and their syntax, tree organization of XML files and industrial standards derived from XML. Second part is devoted to validation of content of XML documents using DTD and XML Schema.

**Integrated Control in Process Industries (2h/week, 6<sup>th</sup> semester)** Process identification from aperiodic or periodic step response. Feedback and feed-forward control. Complex control structures: cascade control, complex control structure with disturbance measurement, complex control structure with auxiliary control input, time-delay compensator - Smith predictor and its modifications, ratio control. Process control: control of tanks, control of mixing units, control of heat exchangers, control of distillation columns, control of chemical reactors, control of dryers. Basic principles of advanced control methods: adaptive control, robust control, predictive control, fuzzy control, artificial neural networks in process control.

**Programming II (1h/week, 6<sup>th</sup> 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, 1<sup>st</sup> and 3<sup>rd</sup> semester)** Introduction to MATLAB and Simulink. Variables, expressions, and operators. Matrices and vectors. Elementary mathematical functions. MATLAB graphics – 2D charts. MATLAB graphics – 3D charts. Polynomials. Custom application creating I. Custom application creating II. Simulink I. Simulink II. Simulink III. Simulink IV.

**Fundamentals of Electrotechnics (2h/week, 2<sup>nd</sup> semester)** Electric circuits - voltage, current. Electric circuits - passive elements. Electric circuits

- active elements. Analysis of electrical circuits. Measurement of electrical circuits. Signal transmission. Signal processing. Measurement of electrical signals - Waveform. Sensors of non-electrical. quantities. Interconnection of sensors and control elements.

**Internet and Information Systems (2h/week, 2<sup>nd</sup> semester)** Information Systems – introduction. Analysis and design of information system. Static websites I – HTML. Static websites II – XHTML. Websites formatting I – CSS. Websites formatting II – CSS. Content Management Systems (CMS, LMS ...). Webhosting and services. Internet services. Cloud computing. Ecommerce. Safety on the Internet. Virtual and remote laboratories.

**Spreadsheet and Database Systems for Data Processing (2h/week, 2<sup>nd</sup> semester)** Introduction to relational databases. MS Access and MySQL. Database design. Database normalization (1NF, 2NF, 3NF, ...). Table creation (fields, data types, indexes, field properties, update). Forms and their elements. Queries. Basics of SQL. Reports. Simple practical application using database. Data processing in a spreadsheet editor (MS Excel). Data processing function. Pivot tables and pivot charts.

**Operating Systems (2h/week, 3<sup>rd</sup> 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, 3<sup>rd</sup> 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.

**Linux – Basic Automation (2h/week, 3<sup>rd</sup> semester)** Bash - recapitulation. Introduction to scripting. Simple tasks - variables, cycles, conditions. Algorithms for more complex tasks. Own script. Presentation.

**Laboratory Exercises of Process Control (2h/week, 4<sup>th</sup> and 6<sup>th</sup> 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. Stability. Reference tracking and disturbance rejection. Analytical methods for controller synthesis. Experimental methods for controller synthesis. Control of tanks. Control of heat exchangers.

**Semestral Project I (3h/week, 4<sup>th</sup> semester)** The main aim of the course is to become familiar with solution and management of projects and to train creativity and self-activity.

**Fundamentals of Embedded System Control (2h/week, 4<sup>th</sup> semester)** Embedded systems - general introduction, characterization, usage in practice. Interaction between embedded system and outside world - introduction to sensors (types and their usage) and actuators (types and their usage). Microcontrollers - general introduction, types and area of usage, principles of operation, advantages and limitations. Microcontrollers - communication scenarios with microcontrollers, programming languages, introduction to programming environment. Introduction to programming language. Programming methods for microcontrollers. Implementation of control logic - introduction to the control algorithms, logical controllers, digital implementation of the PSD controller, digital implementation of the state-space controller and transfer function. Practical applications : object distance measurement using ultrasound. Practical applications : implementation of closed control loops. Realization of final project. Presentation of final project.

**Web Technologies in Automation (2h/week, 4<sup>th</sup> semester)** Introduction to Web Technologies. JavaScript I. JavaScript II. Synchronous and asynchronous communication. HTTP MATLAB Web Server. Virtual monitoring

of laboratory processes. Virtual control of laboratory processes. Remote monitoring of laboratory processes. Remote control of laboratory processes. Industrial implementation of remote control. Final projects realization I. Final projects realization II. Projects presentation.

**Semestral Project II (3h/week, 5<sup>th</sup> semester)** The main aim of the course is to become familiar with solution and management of projects and to train creativity and self-activity.

**Remote Control of Embedded Systems (2h/week, 6<sup>th</sup> semester)** Embedded systems: Repetition - general introduction, characterization, usage in practice; sensors and actuators; microcontrollers. Programming methods for microcontrollers: Recapitulation. Introduction to Web-based communication technologies - HTTP and structures of transferred data (XML, SOAP, JSON), software for emulation of Web services, most commonly used communication scenarios. Methods of communication with control systems - data acquisition from control system, sending data to control system and their processing. Network communication - connection of wired network module to microcontroller, programming of network communication. Wireless Network - connection of wireless networking module to microcontroller, programming of network communication. Connection of control system to the Internet. Remote control of embedded systems via Web Interface - creation of simple Web application for communication with microcontrollers, visualization of process data, process control via Internet. Realization of final project. Presentation of final project.

**Bachelor Project (10h/week, 6<sup>th</sup> 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, 1<sup>st</sup> 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, 1<sup>st</sup> semester)** The students have become familiar with basic principles of identification from aperiodic or periodic step responses. They 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, 1<sup>st</sup> semester)** Automated process control systems. Acquisition and basic processing of process variables. The architecture of measurement systems. Industrial process controllers and stations. Programmable logic controllers. Standard IEC 61131. Distributed control systems. Sensors, actuators, motors, inverters, management.

**Modeling in Process Industry (2h/week, 1<sup>st</sup> 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, 1<sup>st</sup> semester)** Linear dynamical systems. State-space process models. Transfer functions of systems. Time response of linear systems. Frequency analysis. Feedback systems. Lyapunov stability. State controller and observer. Structure of state feedback.

**Process Dynamics and Control (2h/week, 1<sup>st</sup> semester)** Feedback and feed-forward control. Complex control structures: cascade control, complex control structure with disturbance measurement, complex control structure with auxiliary control input, time-delay compensator - Smith predictor and its modifications, ratio control, advanced control methods. Process control: control of tanks, control of mixing units, control of heat exchangers, control of distillation columns, control of chemical reactors, control of dryers.



**Informatization Engineering and Systems I (1h/week, 2<sup>nd</sup> semester)** The course is divided into two parts. The first one deals with the FOXBORO industrial control platform. This part of lectures is devoted to explaining specific aspects of this platform with respect to implementation of control algorithms and creation of graphical user interfaces. Second part, concerned with the SIMATIC platform, which includes overview of ladder logic, implementation of logic and PID control, creation of graphical user interface and their implementation on touch panels.

**Identification (2h/week, 2<sup>nd</sup> 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<sup>nd</sup> semester)** Z-transform. Discrete-time process models. State-space discrete-time models. Transfer functions of discrete-time systems. Stability of discrete-time systems. Design of digital process controllers. DB control. Calculus of variations. Ponryagins principle of minimum. Dynamic programming. Optimal state feedback, LQ control. Kalman filter

**Informatization, Digitalization and Documentation of Heritage (1h/week, 2<sup>nd</sup> semester)** The course is divided into four parts. The first one covers structure of XML documents and their syntax, tree organization of XML files and industrial standards derived from XML. Second part is devoted to validation of content of XML documents using DTD and XML Schema. Third part is concerned with the XPATH technology which allows to search through XML files. The final part deals with transformation of XML documents using XSLT.

**Automatic Control Theory III (2h/week, 3<sup>rd</sup> semester)** Adaptive control (heuristic, self-tuning, MRAC). Multivariable control (RGA analysis, decou-

pling control, MPC). Process control (heat exchangers, distillation columns, chemical reactors, combustion, waste-water treatment plants).

**Informatization Engineering and Systems II (2h/week, 3<sup>rd</sup> semester)** The course is divided into four parts. The first one covers structure of XML documents and their syntax, tree organization of XML files and industrial standards derived from XML. Second part is devoted to validation of content of XML documents using DTD and XML Schema. Third part is concerned with the XPATH technology which allows to search through XML files. The final part deals with transformation of XML documents using XSLT.

**Optimization of Processes and Plants (2h/week, 3<sup>rd</sup> semester)** The main aim of this course is to give basic knowledge about optimization of processes and plants. Process (Plant) optimization is the discipline of adjusting a process (plant) so as to optimize some specified set of parameters. The most common goals are minimizing cost, maximizing throughput, and/or efficiency.

**Predictive Control (1h/week, 4<sup>th</sup> 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 (1h/week, 4<sup>th</sup> semester)** The students know the basic types of uncertainties. They are able to analyze the robust stability of systems with structured uncertainties. They are able to propose a controller for systems with interval parametric uncertainty. The students know how to use linear matrix inequalities in the analysis of robust stability and the design of robust controllers for systems with polytopic uncertainty. The students know unstructured uncertainty. They can analyze the robust stability of systems with unstructured uncertainty and can propose a robust controller for such systems.

**Intelligent Control (1h/week, 4<sup>th</sup> semester)** Students know to apply artificial intelligence methods (methods of patterns recognition, problem solving, expert systems, fuzzy logic, fuzzy modeling and control, artificial neural networks, evolutionary algorithms) to solve problems in the identification, modeling and control of technological processes.

#### 5.4.4 Laboratory Exercises in Master Study

**Information Technology I (2h/week, 1<sup>st</sup> semester)** Introduction to relational databases. Database system MS Access - overview of IDE. Database normalization (normal forms - 1NF, 2NF, 3NF). Table creation (fields, data types, indexes, field properties, update). Relations and reference integrity. Techniques for databases (E-R model). Forms and their elements. Forms and their data. Queries. SQL language I. SQL language II. Reports. Practical application using AIS database.

**Semestral Project I (4h/week, 1<sup>st</sup> semester)** The students have become systematic knowledge of the issues studied and have become familiar with the current state of the field related to the topic of the dissertation thesis. The students are able to classify the different approaches, analyse possibilities of the application and development of these approaches and critically evaluate their advantages and disadvantages. They are able to propose possible solutions and initial experiments focusing on the future thesis. They can conduct initial experiments and evaluated them.

**Professional Training (120h/semester, 2<sup>nd</sup> semester)** Students are able to apply in practice their theoretical and methodological knowledge obtained during university studies. They have validated their knowledge and professional orientation. Students know possibilities of their work in practice.

**Semestral Project II (4h/week, 2<sup>nd</sup> semester)** The students have become systematic knowledge of the issues studied and have become familiar with the current state of the field related to the topic of the project. The students are able to define problems, to choose methods for solving them. The students are able to evaluate the possibility to implement and to develop chosen methods. The students are able to evaluate critically the advantages and disadvantages of the chosen methods. They are able to propose possible solutions and ex-

periments focusing on the future thesis. They can conduct initial experiments and evaluated them.

**Information Technology II (2h/week, 3<sup>rd</sup> 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.

**Process Control Project (3h/week, 3<sup>rd</sup> 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.

**Semestral Project III (4h/week, 3<sup>rd</sup> semester)** The students have become deep systematic knowledge of the issues studied and have become familiar with the current state of the field related to the topic of the project. The students are able to define problems, to choose methods for solving them. The students are able to evaluate the possibility to implement and to develop chosen methods. The students are able to evaluate critically the advantages and disadvantages of the chosen methods. They are able to propose possible theoretical solutions and experiments needed for the confirmation of solvability of defined problems.

**Creation of Scientific Documents (2h/week, 3<sup>rd</sup> 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, 3<sup>rd</sup> 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 and web-based collaboration platforms.

**Network Fundamentals (2h/week, 3<sup>rd</sup> semester)** The focus of this course is on learning the fundamentals of networking. Students will learn both the practical and conceptual skills that build the foundation for understanding basic networking. They will be introduced to the two major models used to plan and implement networks: OSI and TCP/IP. They will become familiar with the various network devices, network addressing schemes, types of media used to carry data across the network, LAN/ WAN technologies and protocols, security and the wireless. This course also introduces to understand how Internet works, how a router learns about remote networks (static and dynamic routing) and how the switch communicates with other switches and routers in the network to implement VLAN segmentation.

**Diploma Project (20h/week, 4<sup>th</sup> semester)** The students can creatively solve problems related to the specified topic. They can do literature search and read, understand and use available technical literary sources in Slovak and English. The students are able to apply the knowledge acquired during their studies. They can plan and execute experiments. They are able to evaluate critically the achieved results and make conclusions. They have learned to create a written documentation of their work. The students are able to defend their results.

## 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 (L. Čírka, M. Fikar, J. Mikleš)** 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, J. Drgoňa, D. Ingole, F. Janeček)** 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, 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 in-



formation 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, L. 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 1/0112/16: Control of Energy Intensive Processes with Uncertainties in Chemical Technologies and Biotechnologies (M. Bakošová)**

Period: 2016 – 2019

The research project deals with the development of advanced control methods for systems with uncertainties and focuses on energyintensive processes in the chemical and biotechnologies such as distillation columns, chemical reactors, biochemical reactors, heat exchangers and other processes. The core of the project consists of development of robust predictive control and fuzzy robust control approaches for systems with uncertainties to ensure the control of processes leading to energy savings compared with traditional approaches. Computational effectiveness and usability in practice will be taken into account in the design of control algorithms for systems with uncertainties. Designed algorithms, controllers and control structures will be tested by simulations and laboratory experiments and will be compared with classical control approaches 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-15-0007: Optimal Control for Process Industries (M. Fikar)**

Period: 2016 – 2020

The main aim of the project is design of effective and advances methods of process control and study of optimal process operation. We will aim our attention mainly to processes with heat and mass transfer. These processes are inherently complex, exhibit nonlinearities and hybrid behaviour that has consequences in control quality and performance. Optimal control will include dynamic optimisation in continuous and discrete domains as a tool for qualitative analysis at upper process control level. Repeated dynamic optimisation at the lower lever yields algorithms of predictive control. This will result in characterisation of optimal operation regimes and controllers optimising processes and large units composed from them. Also important will be software implementation of proposed solutions, available to a larger community in open source code as well as verification in laboratory conditions.

#### **6.2.5 Advanced MPC of Energy-Demanding Chemical Processes (M. Klaučo)**

Internal Grant of the Slovak University of Technology in Bratislava

Period: 2016

This project deals with designing of advanced model predictive control synthesis for energy-demanding chemical processes. Especially in these type of process, the choice of a suitable control strategy is largely affecting the economic aspects of production. The main of such control strategy is to minimize the input raw materials and decrease the maintenance costs. Into the family of energy-demanding chemical, processes belong, for example, the distillation column or steam-gas powerhouses. In these types of processes, even a small reduction of input raw materials has the a huge economic impact.

In this project, we will present a synthesis of an advanced model predictive controller which the main purpose will be to optimize setpoints for current control algorithms. This type of control strategy is called "MPC-based Reference Governor Control". By implementing this kind of controller, we will avoid upgrading current control strategies, which is often costly process. Furthermore, since the advanced MPC controller is an optimization-based control strategy, the use of such strategy naturally leads to optimal plant behavior.

## 6.2.6 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 possibilities 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 criteria, input costs, and energy demands. The unnegligible quality criterion is also the overall computational effort that is minimized. Particular goals of the project are the software tools freely available by Internet.

**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 of 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 simulation of control and control of the real processes.

## 6.3 International Scientific Projects

### 6.3.1 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/>

### **6.3.2 APVV SK-CN-2015-0016: Robust Model Predictive Control Meets Robotics**

Period: 2016 – 2017

Partners:

- Slovak University of Technology in Bratislava (M. Kvasnica, J. Oravec, M. Bakošová, B. Takács, M. Klaučo, J. Drgoňa)
- ShanghaiTech University (B. Houska, X. Feng)

China and Slovakia have an enormous potential for innovative research in robotics and control. The goal of this project is to bring together a group of young researchers whose aim is to create robust model predictive controllers with emphasis on the implementation of advanced control procedures and applications in robotics. We will build upon advanced linear matrix inequality techniques and real-time control software to develop novel types of autonomous and intelligent control algorithms for uncertain processes that are far beyond the state-of-the-art. The research shall be carried out by scientist and PhD students in Slovakia and China, who will visit each other on a regular basis, thereby creating channels for technological as well as intercultural exchange. At the same time, we will showcase innovative research on modern technologies that shall educate the next generation of control and robotic sci-

entists in China and Slovakia, thereby creating a huge potential for academic breakthroughs as well as successful spin-offs in both countries.

### **6.3.3 APVV SK-FR-2015-0001: Real Time Optimal Process Control**

Period: 2016 – 2017

Partners:

- Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Department of Inform. Eng. and Process Control (M. Fikar, M. Jelemenský, D. Pakšiová, A. Sharma)
- Institut National Polytechnique de Lorraine (INPL) - Ecole Nationale Supérieure des Industries Chimiques (ENSIC) (M. A. Latifi, F. Lesage, R. Hriez, R. Bousbia-Salah)

Finding the optimal solution to a problem is an every day struggle. The mankind has been in search of optimality to any problem in every aspect of life such as work. These optimization problems can differ in many aspects. For example in research work we want to find the optimal control for distillation columns, heat exchangers or membrane processes to maximize the profit and the minimize the production costs. In normal life we can also face many optimization problems without realizing it. These can be for example which way should I choose to come to work in minimum time. To solve all these optimization problems we can use several optimization methods from the field of dynamic optimization. In this research project we will focus mainly on the chemical processes.

### **6.3.4 SK06-II-01-004: Support of international mobilities between STU Bratislava, NTNU Trondheim, and Universität Liechtenstein**

Period: 2.6.2015 - 30.9.2016

Partners:

- Slovak University of Technology in Bratislava: UAMT FEI STU (prof. Huba coordinator), UAMAI Sjf STU (prof. Rohal-Ilkiv), UIAM FCHPT STU (prof. Fikar), DBS SvF STU (doc. Rabenseifer)

- Norwegian University of Science and Technology Trondheim (prof. Skogstad, prof. Johansen, prof. Hovd)
- Universität Liechtenstein, Liechtenstein (prof. Droege)

The aim of the project is to support international mobility of students, PhD students, and staff members of four participating faculties of STU in Bratislava with partners from NTNU Trondheim and Universität Liechtenstein. It will initiate academic cooperation between the University of Liechtenstein and STU Bratislava in construction, architecture, and space planning, focusing on the use of alternative energy sources in operation of buildings, including computer-aided simulations of energy needs and internal environment, and spatial planning of rural settlements as well. The project also contributes to further strengthening of already existing cooperation between NTNU Trondheim and faculties of STU in Bratislava in the field of advanced methods of automatic control and to progress of inter-faculty cooperation at STU in Bratislava.

## 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)
- Department of Mechanical Engineering, Division of Applied Mechanics and Energy Conversion (TME), KU Leuven - University of Leuven, Leuven, Belgium (Simulation of Thermal Systems)



- 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 Supérieure 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, L. 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)
- 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)

- Artzová, P. Modeling of the Processes in Chemical Industries and Controller Design Using UniSim Design (Oravec, J.)
- Boloz, M. Creation of Remote HMI in SCADA System PROMOTIC (Valo, R.)
- Čizmazia, O. Mathematical Modelling of Membrane Processes (Valo, R.)
- Hamerlik, E. Support Vector Machines for Data Classification (Kvasnica, M.)
- Hanulová, L. Identification and Controller Design for a Laboratory Chemical Reactor (Oravec, J.)
- Hornák, M. Fuzzy Control of the Distillation Column (Takáč, Z.)
- Hronec, R. PID Controller Design Using Multiple Dominant Pole method (Vasičkaninová, A.)
- Kukla, J. The Control of MIMO Chemical-Technological Process Using PID and LQR Controllers (Fikar, M.)
- Mamarasulov, J. User Interface for Intelligent Thermostats (Kvasnica, M.)

### 8.2 Master Theses (MSc. degree)

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

Benkovský, M.	Remote Laboratory of Discrete Time Model of a Chemical Reactor (Kalúz, M.)
Janeček, F.	MPC for Autonomous Vehicles with Collision Avoidance (Kvasnica, M.)
Jaroš, B.	Industrial Control of Thermo-Optical Plant uDAQ28/LT (Valo, R.)
Kamenický, A.	Control of a Distillation Column Using Honeywell's Solutions (Fikar, M.)
Krippel, M.	Information System IIEAM (Čirka, L.)
Lacková, Z.	SCADA System Production in STEP 7 TIA Portal (Valo, R.)
Miklovič, T.	Visualization of Charge Density (Gall, M.)
Míková, N.	Design of Simulink Diagram via the Internet (Čirka, L.)
Némethová, T.	Analysis of Wood Fibers Using Color Photography (Števek, J.)

### 8.3 PhD's Theses (PhD. degree)

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

Holaza, J.	Fast and Memory-Efficient Implementation of Model Predictive Control (Kvasnica, M.)
Jelemenský, M.	Optimal Control of Membrane Processes in the Presence of Fouling (Fikar, M.)
Takács, B.	Synthesis and Implementation of Model Predictive Control (Kvasnica, M.)

## 9 Publications

### 9.1 Book

1. Paulen, R. - Fikar, M.: **Optimal Operation of Batch Membrane Processes**, Springer, 2016.

### 9.2 Chapters or Pages in Books

1. Bakošová, M. - Vasičkaninová, A. - Oravec, J.: *Use of advanced control strategies to ensure energy savings (in Slovak)*, In *Efektívne využívanie zdrojov a surovín*, Editor(s): OndrejKovičová I., Izakovič M., Slovenská chemická knižnica FChPT STU v Bratislave, pp. 135–157, 2016.

### 9.3 Articles in Journals

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