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

ANNUAL REPORT

2021

Address:

Department of Information Engineering and Process Control
Institute of Information Engineering, Automation, and Mathematics

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Absent: J. Mikleš, C. E. Valero, T. Ábelová, A. Vasičkaninová

Contents

1 Preface

The Department of Information Engineering and Process Control at the Faculty of Chemical and Food Technology of the Slovak University of Technology in Bratislava has more than a fifty-year tradition in conducting teaching and research. It educates highly qualified specialists in the process control design, implementation, and application of control systems. The educational pyramid includes a three year bachelor study in the study program called Information Engineering, Automation and Management in Chemical and Food Industry, a 2-year master study in the program Information Engineering and Automation in Chemical and Food Industry, and a four year doctoral study in the program Process Control.

Nowadays, information technologies and advanced process control systems represent vital and acknowledged scientific branches. These branches significantly influence the economic and social growth in the whole world and successively also in Slovakia. The chemical, food processing, 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.

The department's main branch of teaching and research activities is oriented towards process control, optimization-based control design, identification and modeling of dynamical systems, industrial automation, and the development of software packages for intelligent control systems. We also acknowledge recent trends that occur in scientific and industrial practice in incorporating knowledge about machine learning and data science in our research and teaching activities. The second branch is devoted to information technologies, data management, and programming.

Our department, therefore, prepares our graduates to be competitive in this dynamical and demanding environment. As a sign of our success, let me point out the zero unemployment rate of our graduates during our department's whole history. The department graduates do well in companies and institutions oriented on the design and installation of control systems for various technologies and in the fintech sector or as founders of their own companies.

As of September 2020, I was appointed by M. Kvasnica as the new head of the department. Together with my deputy R. Paulen, we will continue in close cooperation with our colleagues to increase the quality of both research and teaching domains.

Ing. MSc. Martin Klaučo, PhD.

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 1st – December 31st of 2021.

Department of Information Engineering and Process Control of the Faculty of Food and Chemical Technology (FCFT), Slovak University of Technology 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 hundred specialists and almost thirty PhD students have been graduated here and four 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 prof. Alojz Mészáros, PhD. Prof. Ing. Miroslav Fikar, DrSc. was head of the department in 2003 – 2019 and doc. Ing. Michal Kvasnica, PhD was head of department in 2019 – 2020. Current of the department is Ing. MSc. Martin Klaučo, PhD.

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 1,150 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 M.Sc. degree. The best ones continue in the four-year doctoral programs leading to the PhD degree.

3 Staff

3.1 Head of Department

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4 Teaching and Research Laboratories

Laboratory of Process Control: Control of specific processes via Matlab and internet access (elab)

- Distillation Column Armfield UOP3CC (elab)
- Membrane Process SUPER RO BM 30 (elab)
- Multifunction Station Armfield PCT40 (elab)
- Hydraulic System with Storage Tanks DTS200
- Training Station Armfield PCT23 (elab)

Laboratory of Control Systems:

- Lego Mindstorms NXT 2.0
- Thermo-optical System uDAQ28/LT
- Flexy
- Laboratory Food Machine
- Linear Inverted Pendulum
- Rotary Inverted Pendulum (Furuta)

Laboratory of Industrial Technology:

- Siemens-SIMATIC S-7 200, 300, 1200
- FOXBORO
- B&R
- VIPA 300S
- eWONx005CD
- Experion/Honeywell

Computer Laboratories:

- Linux based PCs
- Raspberry Pi
- Arduino
- Moving Robots (cars)
- 2D Plotter
- 3D Printer

5 Educational Activities

5.1 Bachelor Study

1st semester (Winter)		
Fundamentals of Matlab	0/0/2	Dzurková, Kiš
Tools of Technical Computing I	0/2/0	Kiš
2nd semester (Summer)		
Information Engineering and Systems	1/2/0	Kalúz
Internet and Information Systems	0/0/2	Čirka
Spreadsheet and Database Systems for Data Processing	0/0/2	Čirka
3rd semester (Winter)		
Computer-based Simulation	1/0/1	Paulen
Informatics II	0/0/2	Valo
Modelling of Processes in Chemical and Food Technology	2/0/2	Mészáros, Vasičkaninová
Operating Systems I	0/2/0	Valo
4th semester (Summer)		
Fundamentals of Embedded System Control	0/0/2	Kalúz, Furka
Introduction to Process Control	1/0/1	Klaučo, Fedorová
Laboratory Exercises of Process Control	0/0/2	Horváthová, Galčíková, Vašičkaninová
Process Control	2/0/0	Oravec
Programming I	2/0/2	Kvasnica, Fedorová
Web Technologies in Automation	0/0/2	Čirka
5th semester (Winter)		
Distributed version control system	0/2/0	Oravec

Optimization	2/2/0	Kvasnica, Horváthová
Presentation skills II	0/2/0	Klaučo
Programming II	0/2/0	Kohút

6th semester (Summer)

Integrated Control in Process Industries	2/0/3	Bakošová, Vasičkaninová
Programming II	1/2/0	Kvasnica, Kohút

5.2 Master Study

1st semester (Winter)

Automatic Control Theory I	2/0/3	Fikar, Galčíková, Klaučo
Industrial Control Systems	0/0/2	Valo
Information Technology I	0/0/2	Dzurková
Modelling in Process Industry	2/2/0	Bakošová, Vasičkaninová
Process Dynamics and Control	2/0/1	Bakošová, Vasičkaninová
Semestral Project I	0/0/4	Kalúz, Klaučo, Kohút, Oravec

2nd semester (Summer)

Automatic Control Theory II	2/0/3	Fikar, Čirka
Identification	2/0/2	Paulen, Mojto
Informatization Engineering and Systems I	1/0/3	Kalúz, Valo
Semestral Project II	0/0/4	Čirka

3rd semester (Winter)

Automatic Control Theory III	2/0/2	Fikar, Horváthová, Mojto

Creation of Scientific Documents	0/2/0	Mojto
Optimisation of Processes and Plants	2/0/2	Kvasnica, Fedorová, Kohút
Process Control Project	0/0/3	Oravec, Bakaráč
Project Software Systems	0/2/0	Oravec

4th semester (Summer)

Diploma Thesis	0/0/20	Čirka
Intelligent Control	1/2/0	Kvasnica, Kohút
Predictive Control	1/2/0	Klaučo, Kiš
Robust Control	1/2/0	Bakošová, Oravec

1st semester (Winter)

Programming of Web Applications I	1/0/2	Čirka
Technical Means of Automation I	2/0/2	Kalúz, Bakaráč, Furka

3rd semester (Winter)

Programming of Web Applications II	2/0/2	Čirka, Klaučo

5.3 PhD Study

1st year

Modelling and Control of Biotechnological Processes	2/0/3	Bakošová
Modelling 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	Mészáros
Selected Topics in the Theory of Automatic Control	2/0/3	Paulen

5.4 Course Contents

5.4.1 Lectures in Bachelor Study

Dynamic Systems (2h/week, 2nd semester) Definition of a system. Definition of a dynamic system. Definition of a static system. Definitions of inputs, outputs and states of a dynamic system. Mathematical representation of dynamic systems. Types of mathematical models of dynamic systems. State space. Order of a dynamic system. Applications of mathematical representation of dynamic systems. Basic definitions from control of dynamic systems. Linearity, autonomy, causality and time invariance of dynamic systems. Equilibrium state of a dynamic system. Stability of equilibrium state of a dynamic system. Behavior of a system in the neighborhood of an equilibrium state. Stability of a dynamic system. Applications of dynamic system properties for monitoring and control of systems. Applications of control of dynamic systems.

Modelling of Processes in Chemical and Food Technology (2h/week, 3rd semester) Introduction to process modeling, approaches to modeling, types of mathematical models. Nonlinear state-space model, linear state-space model, transfer function. Static and dynamic mathematical models of basic types of chemical and food technology processes: tanks for liquid storage, blenders, jacketed heat exchangers, flow heaters, recuperative heat exchangers, continuous stirred tank chemical reactors. MATLAB and Simulink software and its use for creating a nonlinear and linear process model, calculation and plotting of static process characteristics, simulation of transient characteristics of storage tanks, heat exchangers and chemical reactors using nonlinear and linear models. Evaluation and comparison of static and dynamic properties of processes.

Web Technologies I (1h/week, 3rd semester) The course is focused on development of web pages and it is divided into four main parts. First three parts are dedicated to technologies HTML, CSS and JavaScript, which are the main languages used for definition of content, design, and functionality of web pages. The last part is dedicated to production of complex web pages using the content management system Wordpress.

Computer-based Simulation (1h/week, 3rd semester) The course is divided into two main parts. The first part is devoted to the study of methods for numerical solution of algebraic equations with emphasis on the identification of steady states of dynamical systems. The second part deals with the study of methods for the numerical solution of ordinary differential equations with main stress on the properties of dynamical systems.

Introduction. Types of mathematical models and their computer representation. Steady states of linear dynamical systems and their numerical identification. Steady states of nonlinear dynamical systems and their numerical identification. Steady states of nonlinear dynamical systems and their numerical identification – Newton's method. Steady states of nonlinear dynamical systems – multidimensional systems and multiple steady states. Introduction to ordinary differential equations. Analytical solution. Numerical solution of ordinary differential equations. Explicit Euler's method. Implicit Euler's method. Runge-Kutta methods. Implicit methods. Adams method. Collocation methods.

Process Control (2h/week, 4th semester) Laplace transform Transfer function and transfer functions of complex systems Step response Poles and zeros Modeling of tanks PID controller Feed-back control loop and stability Reference tracking and disturbance rejection Control performance Analytical methods for controller synthesis Experimental methods for controller synthesis Sensors and measurement of the controlled variables Technological schemes with measurement and control loops

Logic Control (2h/week, 4th semester) The course is divided into three parts. The first one is dedicated to design of a logic control using finite-state machines (FSM) and its practical implementation in Stateflow. Second part is focused on programmable logic controllers (PLC) that represent a standard for control of machines and processes in manufacturing industries. In the last part, students will work on a selected laboratory project.

Web Technologies II(1h/week, 4th semester) This course is devoted to the design of web-based information systems, and is divided intro three main parts. The first part is devoted to programming in PHP language with the connection to MySQL programming. During the second part, modern PHP frameworks are taught. The third part covers the fronted design in JavaScript, HTML and CSS. By completing this course, students are capable to combine all three mentioned software programming tools and they are capable of building standalone web-based application.

Optimization (2h/week, 5th semester) This course introduces basic mathematical formulations of optimizations tasks, ranging from simple ones (without any constraints), up to complex ones (with equality and inequality constraints); explains which algorithms are available to solve particular types of optimization problems; and introduces how the optimal solution is to be interpreted from an economic perspective.

Parameter Estimation (1h/week, 5th semester) The course is divided into two main parts. The first part introduces into basic and advanced concepts of statistical parameter estimation. Second part concentrates on parameter estimation for dynamic systems.

Database systems (1h/week, 6th semester) The course is divided into three parts. The first part is focused on databases and data modeling in general. The second part forms the core of the course. It deals with the SQL language. The third part is practically oriented. In this part, students work in MySQL and MS Access databases.

Introduction, motivation and basic concepts of database systems Data modeling (Conceptual model, Logical model, Physical model) Database normalization SQL language (DDL, DML, Constraints, Views, Functions) MySQL (phpMyAdmin, Tables, Queries) MS Access (Tables, Forms, Queries, Reports, VBA) Non-relational database systems (NoSQL)

Process Control II (2h/week, 6th semester) Process identification from aperiodic or periodic step response. Process identification from astatic step response. Methods for PID controller tuning. Quality criteria. 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 blenders, control of heat exchangers, control of pipelines, control of chemical reactors, control of biochemical reactors, control of neutralization processes. Actuators.

Introduction to Optimal and Predictive control (1h/week, 6th semester) The subject is divided into three main parts. The first is devoted to the introduction of optimal control and basic mathematical formulations of optimal control problems. The second part describes the mathematical foundations

of formulating predictive control problems as convex optimization problems. The last part deals with the applications of individual applications of optimal control strategies in industry and to practical examples.

5.4.2 Laboratory Exercises in Bachelor Study

Electrical engineering (2h/week, 1st semester) Basic knowledge about electric circuits and their individual components and how to use various methods to analyze and validate electric circuits. Overview of the principles of transmitting information (signals) via electric circuits. Basic signal processing and conditioning and integration of sensors into control systems. Practical skill in soldering, reading and understanding datasheets, and compiling technical documentation for electric circuits.

Process control seminar (2h/week, 1st semester) Introduction to process control. Basic terms – controlled process and its dynamics. Basic terms – sensors and actuators. Basic terms – regulator and constraints. Overview of hardware and software implementation of control systems. Overview of advanced control methods. Success stories – chemical industries. Success stories – food industries. Success stories – paper industries. Success stories – automotive. Success stories – robotics. Success stories – building control.

Informatics I (2h/week, 2nd semester) Computer architecture. Layered architecture and structure of folders. Functionality and architecture of laboratory management information systems. Spreadsheet MS Excel. Address space organization of MS Excel, mathematical and statistical functions. Structured constructions, data analysis methods, charts, matrices and equation solving. Text editor MS Word, formatting and styles. Chemical and mathematical texts, tables. Advanced functions and academic writing. Presentation and visualization, graphical and presentation software.

Embedded Systems I (2h/week, 2nd semester) The course is divided into three parts. First part is focused on understanding the basic working principles of microcontroller platforms, electric circuits for sensing and control of physical processes, and getting acquainted with programming tools. Second part is practically oriented. In this part, students implement and program typical applications on microcontrollers. In the first two parts, students will also learn the basics of programming in C language. Third part is dedicated to individual projects, their presentation and defense.

Introduction to the R language (2h/week, 2nd semester) The R environment, related software and documentation, R and statistics. Simple manipulations & numbers and vectors: vectors and assignment, vector arithmetic, logical vectors, character vectors, index vectors. Objects and attributes: arrays and matrices, array indexing, index matrices. Lists and data frames: constructing and modifying lists, making data frames, working with data frames. Reading data from files: loading data from other R packages editing data. Writing your own functions: simple examples, more advanced examples Recursive numerical integration, graphics, shiny server.

Modeling of Processes in Chemical and Food Technology (2h/week, 3rd semester) The curriculum of exercises follows the topics of lectures of this course.

Web Technologies I (3h/week, 3rd semester) The curriculum of exercises follows the topics of lectures of this course.

Informatics II (2h/week, 3rd semester) Automated task processing, scripting languages in Linux and Windows operating systems. Batch document creation and treatment. Typesetting using LaTeX (introduction, document classes, simple and mathematical environments, graphics, links, bibliography). Foundations of versioning systems.

Tools of Technical Computing III (2h/week, 3rd semester) This course offers practical experience with basics of data science (random variables, correlation analysis), machine learning (supervised and unsupervised learning) and creation of graphical user interfaces in the MATLAB environment. These three domains constitute the main parts of the course.

Random variables. Statistical probability distribution. Basic calculations of statistical analysis – average, median, moving average and median. Advanced calculations of statistical analysis – correlation, covariance matrix, correlation matrix. Methods of unsupervised machine learning. Principal component analysis. Data filtering. Linear regression. Nonlinear regression. Artificial neural networks. Deep artificial neural networks. Introduction to graphical user interface. Creating own applications using a graphical user interface.

Computer-based Simulation (1h/week, 3rd semester) The curriculum of exercises follows the topics of lectures of this course.

Embedded Systems II (3h/week, 3rd semester) The course is divided into four parts. First part is focused on understanding advanced working principles of microcontroller platforms. The second part is dedicated to utilization of microcontrollers on the Internet of Things, with focus on standard architectures, communication interfaces, protocols, databases, and Cloud solutions. Third part is practically oriented. In this part, students implement typical microcontroller applications for the Internet of Things. Fourth part is dedicated to individual projects, their presentation and defense.

Operating Systems I (2h/week, 3rd semester) The course is divided into three main parts. The first is devoted to the basics of work in UNIX-type operating systems, as well as working with files and directories, archiving, searching, processing text files and remote computers. The second part is dedicated to the connection, installation, configuration and administration of your own UNIX-type system on a designated HW platform. The last part is focused on versioning tools such as GitHub.

Process Control I (2h/week, 4th semester) MATLAB programming environment. Solving Differential equations using Laplace transform – different real roots. Solving Differential equations using Laplace transform – multiple real roots. Transfer functions algebra. System properties – poles and zeroes. Model of liquid tanks. Closed-loop system stability. Control performance. Control of liquid tanks – analytical methods for controller design. Control of the selected system – experimental identification and controller tuning.

Team project (4h/week, 4th semester) Assignment of the topic of the team project in the field of automation and informatization in chemistry and food industry. Selection of the optimal composition of the team while considering strengths and weaknesses. Selection of a suitable software platform for project planning and checking of plan fulfilment. Selection of a software platform for team collaboration (shared calendars, shared disk drives, wikis, etc.). Literature review and study of the field of the project. Group consultations on the topic of the project. Problem analysis, team-based problem solving, written and oral presentation of the results obtained in solving the problem.

Assignment of the topic of the team project. Selection of the optimal composition of the team. Selection of software platforms and tools for collaboration. Literature survey and problem study. Consultations on the topic of the project. Problem analysis. Team-based problem solving. Written and oral presentation of the results.

Logic Control(2h/week, 4th semester) The curriculum of exercises follows the topics of lectures of this course.

Programming I(2h/week, 4th semester) This course introduces fundamentals of the Python programming language, demonstrates its internal data types, shows how to manipulate data using functions and methods, explains different ways in which users can interact with the program, shows how external files can be accessed, and how external modules and libraries can be utilized.

Tools of Technical Computing IV (2h/week, 4th semester) The subject is divided into three main parts. The first one is devoted to an introduction to probability and statistics with emphasis on the probability distribution of a random variable, density and distribution function. The second part deals with statistical analyzes of one-dimensional data, especially interval estimates of parameters and testing of hypotheses. In the last part, statistical analyzes of multidimensional data such as correlation analysis, regression models, ANOVA or time series analysis are studied.

Operating Systems II (2h/week, 4th semester) The course is divided into two main parts. The first is devoted to the syntax and application of basic elements of algorithms such as variables, conditions and cycles. The second is devoted to the design of algorithms and their implementation in the form of scripts

Production of Audiovisual Works (2h/week, 4th semester) The course is focused on production of audiovisual works, specifically the video, audio, and photography. First two parts are dedicated to mastering the fundamental terms and principles of video, audio, and photo equipment operation (performed on practical examples). In the third (main) part of course, the students are assigned into teams and they work on production of audiovisual materials. In this part, the students master techniques of scene and screenplay preparation, video shooting, digital post-production and publishing of videos. This part also includes the photo shooting and photo editing.

Spreadsheet and Database Systems for Data Processing(2h/week, 4th semester) Introduction to relational databases: What is a database? Why to use a database? MS Access and MySQL databases. Database design: Database normalization (1NF, 2NF, 3NF). Table creation (fields, data types, indexes, field properties, update). Forms and their elements: Form creation. Form controls configuration. Form formatting. Queries: Basic queries creation. Data sorting and filtration in a query. Calculations in a query. Basics of SQL. Reports: Report creation. Adding controls to a report. Report formatting. Simple practical application using database. MS Excel: Data processing function. Pivot tables and pivot charts. Macros.

Optimization (2h/week, 5th semester) The curriculum of exercises follows the topics of lectures of this course.

Presentation skills II (2h/week, 5th semester) The course is divided into 3 parts. In the first part of the course, students acquired knowledge from the preparation of typographically perfect documents in the LaTeX environment. The second part is devoted to the preparation of a typographically high-quality presentation and posters in the LaTeX environment. By completing this part, students gained knowledge of creating documents, generating PDF outputs from the LaTeX environment, as well as working with tables and graphs in vector format. In the third part of the course, students will gain knowledge of the preparation of infographics and diagrams in a vector graphics editor (eg Inkscape). Students learned to work with basic vector structures, their placements and export to a vector format. Students learned to integrate their workflow between Matlab, a graphical editor and the LaTeX environment. In this course, students performed oral presentations with discussion in front of the audience to improve their presentation and soft skills.

Semestral Project (3h/week, 5th semester) Assignment of the topic of a semester project. Literature survey and problem study. Consultations on the topic of the project. Problem analysis. Independent problem solving. Written and oral presentation of the results.

Parameter Estimation (1h/week, 5th semester) The curriculum of exercises follows the topics of lectures of this course.

Programming II (2h/week, 5th semester) This course introduces advanced aspects of Python programming, which include, but are not limited to: exceptions, functions to manipulate objects of the operating system, functions of the numpy library for technical computing, functions of the matplotlib library for data visualization, and functions of the scipy library for scientific computing.

Data structures and algorithms(2h/week, 5th semester) The course introduces fundamentals basic data structures that are used in efficient algorithms, shows the concept of modular arithmetics that is often used in cryptography, discusses divide-and-conquer algorithms, sorting methods, Fourier transform, Huffman encoding, algorithms for efficient searching in graphs, as well as quantum algorithms.

Distributed version control system(2h/week, 5th semester) The framework of the distributed version control Software tools for distributed version control Basic repository configuration Advanced repository configuration User interface configuration Configuration of the users' access Basic file management Advanced file management Team project focused on file management Basic commit management Advanced commit management Team project focused on commit management

Bachelor Thesis (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.

Process control project (4h/week, 6th semester) Assigning the roles in the team, designing the project agenda, and time management of the particular tasks Literature review on the selected process and considered control method Model design Model validation Controller design Simulation of the closed-loop control Setting up the laboratory plant Measurement of experimental results on laboratory plant Controller tuning Analysis of the control performance Data processing and formulation of conclusions Creating the presentation of the results

Database systems (3h/week, 6th semester) The curriculum of exercises follows the topics of lectures of this course.

Process Control II (2h/week, 6th semester) The curriculum of exercises follows the topics of lectures of this course.

Industrial Technologies (2h/week, 6th semester) The course is divided into two main parts. The first part is devoted to an overview of technologies used in individual layers of the automation pyramid. The second is devoted to the implementation of the acquired knowledge on various experiments.

Introduction to machine learning (2h/week, 6th semester) The course is divided into 4 parts. The first part is focused on data processing, formatting and analysis of the datasets. The second part is dedicated to the introduction and implementation of some machine learning models. The third part is dedicated to the introduction and implementation of artificial neural networks with basic and complex formulations. The last part is dedicated to final group projects, where the theoretical and practical skills gained from previous parts are applied.

Introduction to Optimal and Predictive control (1h/week, 6th semester) The curriculum of exercises follows the topics of lectures of this course.

Introduction to the Julia language (2h/week, 6th semester) This course introduces fundamentals of the Julia programming language, demonstrates its internal data types, shows how to manipulate data using functions and methods, explains different ways in which users can interact with the program, shows how external files can be accessed, and how external modules and libraries can be utilized.

5.4.3 Lectures in Master Study

Automatic Control Theory I (2h/week, 1st semester) Linear dynamical systems. State-space process models. Transfer functions of systems. Time response of linear systems. Frequency analysis. Continuous-time control. State controller and observer. Structure of state feedback.

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

Object Oriented Programming (1h/week, 1st semester) Terms, cycles, functions, directives, foundations of structure use, simple matched lists, classes and methods of classes, inheritance and polymorphism.

Programming of Web Application (1h/week, 1st semester) Repetition of XHTML and CSS languages, creation of static web pages, mastering and advanced work with PHP language, creation of custom functions, introduction to databases, SQL databases, MySQL database.

Technical Means of Automation (2h/week, 1st semester) Introduction to the course – Presentation of course's topics. Fundamentals of electricity and electric signals Sensors – measurement of process quantities. Static and dynamic characteristics of sensors. Temperature sensors. Pressure sensors. RC circuits and noise filters. Measurement of mechanics and physical properties of fluids. Actuators – control of technological processes. DC motors. AC motors. Valves and pumps. Industrial control systems. Introduction to digital control systems. Programmable logic controllers (PLC). PLC programming, ladder logic and ladder diagrams. Program organization in PLC. Industrial networks. Digital implementation of control.

Automatic Control Theory II (2h/week, 2nd semester) Discrete-time control. Z-transform. Discrete-time dynamic systems. Properties of discrete-time dynamic systems. Control design for discrete-time systems. Optimal Control.

Optimisation and optimal control. Calculus of variations. Pontryagin's principle of minimum. Dynamic programming. Optimal state observers.

Identification (2h/week, 2nd semester) Introduction to identification, basic terms, subject of system identification. Identification procedure, structure selection, verification, input signals. Step responses, 1st order model. Step responses, 2nd order model. Step responses, higher order models. Autotuning. Frequency analysis, construction of frequency responses, estimation of transfer functions. Regression methods, estimation of parameters, identification of static models. Regression methods, identification of dynamic models. Recursive least squares, model identifiability, modifications of RLS. Recursive LS, continuous-time models. Models of linear dynamical systems, model verification. Practical issues in identification.

Informatization Engineering and Systems I (1h/week, 2nd 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.

Automatic Control Theory III (2h/week, 3rd semester) Adaptive control (heuristic, self-tuning, MRAC). Multivariable control (RGA analysis, decoupling control, MPC). Process control (heat exchangers, distillation columns, chemical reactors, combustion, waste-water treatment plants).

Informatization Engineering and Systems II (2h/week, 3rd 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, 3rd 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.

Programming of Web Applications II (2h/week, 3rd semester) PHP framework installation and setup, Database installation and setup, Database design, Object-oriented programming, MVC architecture, Form and validation, Authorization and authentication, Internationalization and localization, Framework and JavaScript, Document generation (PDF, XLSX, ...), Creating a simple application

Fundamentals of Fuzzy Systems (2h/week, 3rd semester) Fuzzy sets – basic notions, Fuzzy logic, Fuzzy arithmetic, Fuzzy relations, Fuzzy reasoning, Applications of fuzzy sets and fuzzy logic in fuzzy systems

Diploma Thesis (1h/week, 4th semester) Specification of the thesis topic. Study of the available literature and processing of sources from the literature. The choice of the theoretical approach and methodology to solving the problem and planning experiments. Conducting of experiments and critical evaluation of obtained results. Writing of the final thesis. Defence of the diploma thesis.

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

Predictive Control (1h/week, 4th semester) The course is divided into three main parts. The first one introduces the concept of model predictive control (MPC) and shows its analogies to optimal control. Second part describes mathematical fundaments required to formulate MPC problems as convex optimization problems. The final part discusses various formulations of MPC, including regulation towards non-zero references, removal of regulation offsets, and output regulation.

Robust Control (1h/week, 4th semester) Introduction to robust control. Systems with single parameter uncertainty. Systems with interval parametric uncertainty. Robust controller design for systems with interval uncertainty.

Systems with linear affine uncertainty. Stability of Polytopic systems. Multilinear uncertainty. Generalized Kharitonov theorem. LMI in robust control. Robust pole-placement method. Introduction to unstructured uncertainty. Unstructured uncertainty – analysis and synthesis.

5.4.4 Laboratory Exercises in Master Study

Automatic Control Theory I (3h/week, 1st semester) The curriculum of exercises follows the topics of lectures of this course.

Modelling in Process Industry (2h/week, 1st semester) The curriculum of exercises follows the topics of lectures of this course.

Object Oriented Programing (2h/week, 1st semester) The curriculum of exercises follows the topics of lectures of this course.

Object Oriented Programming (3h/week, 1st semester) The curriculum of exercises follows the topics of lectures of this course.

Programming of Web Application (2h/week, 1st semester) The curriculum of exercises follows the topics of lectures of this course.

Semestral Project I (4h/week, 1st 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.

Technical Means of Automation (2h/week, 1st semester) The curriculum of exercises follows the topics of lectures of this course.

Automatic Control Theory II (3h/week, 2nd semester) The curriculum of exercises follows the topics of lectures of this course.

Identification (2h/week, 2nd semester) The curriculum of exercises follows the topics of lectures of this course.

Informatization Engineering and Systems I (3h/week, 2nd semester) The curriculum of exercises follows the topics of lectures of this course.

Professional Training (120h/semester, 2nd 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, 2nd 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 experiments focusing on the future thesis. They can conduct initial experiments and evaluated them.

Automatic Control Theory III (2h/week, 3rd semester) The curriculum of exercises follows the topics of lectures of this course.

Information Engineering and Systems II (2h/week, 3rd semester) The curriculum of exercises follows the topics of lectures of this course.

Fundamentals of Fuzzy Systems (2h/week, 3rd semester) The curriculum of exercises follows the topics of lectures of this course.

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.

Network Fundamentals (2h/week, 3rd 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 introduce to understand of 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.

Optimization of Processes and Plants (2h/week, 3rd semester) The curriculum of exercises follows the topics of lectures of this course.

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.

Project Software Systems (2h/week, 3rd semester) Introduction to version management, examples from practice, centralized vs. decentralized access, CVS, SVN, git and Mercurial, graphical user interfaces.

Semestral Project III (4h/week, 3rd 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.

Diploma Project (20h/week, 4th 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.

Intelligent Control (2h/week, 4th semester) The curriculum of exercises follows the topics of lectures of this course.

Predictive Control (2h/week, 4th semester) The curriculum of exercises follows the topics of lectures of this course.

Robust Control (2h/week, 4th semester) The curriculum of exercises follows the topics of lectures of this course.

6 Current Research Activities

Research at the Department of Process Control orients to advanced control theory and modelling of chemical and biochemical processes. Current research areas, among other research fields, include optimization, model predictive control, robust control, etc. Previously members of the department focused also on adaptive control and identification.

6.1 Main Research Areas

Modeling and Simulation (M. Bakošová, A. Vasičkaninová) Modelling 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 modelling 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. Also, Honeywell's UniSim Design Suite is an intuitive process modelling software that helps engineers create steady-state and dynamic models for plant design, performance monitoring, troubleshooting, business planning and asset management.

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. Kvasnica, M. Klaučo, J. Oravec, P. Bakaráč, M. Furka, M. Horváthová, K. Fedorová, R. Kohút, L. Galčíková) Model Predictive Control (MPC) is widely studied advanced control strategy in roots in Dynamic Matrix Control. The focus in this research domain is divided into two main areas, the first being the online MPC and the second is the explicit MPC. Theoretical and practical aspects of the MPC strategy are studied. The online MPC discipline covers design and implementation of MPC strategies

based on linear, quadratic and mixed-integer programming. The second area includes parametric programming and development of Multi-Parametric Toolbox[1].

Dynamic Optimisation (M. Fikar, R. Paulen, M. Mojto) 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. We study membrane processes, multicomponent distillation, waste-water treatment, etc.

Robust Control (M. Bakošová, J. Oravec, A. Vasičkaninová, M. Horváthová, L. Galčíková) 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, P. Bakaráč) Research in this domain focuses on application of information technologies in control education. This covers interactive on-line blocks, automatic generation of testing problems, development of educational process plants.

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

[1] M. Herceg, M. Kvasnica, C.N. Jones, and M. Morari. Multi-Parametric Toolbox 3.0. In Proc. of the European Control Conference, pages 502–510, Zurich, Switzerland, July 17–19 2013. http://people.ee.ethz.ch/~mpt/3/

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

Machine Learning in Process Control (M. Kvasnica, M. Klaučo, M. Kalúz, K. Kiš) Machine learning is attracting huge interest not only in academia but also in the industry. The primary aim of this research is to study the application of machine learning approaches to enhance and design controllers of various nature and structure.

Guaranteed Parameter Estimation (R. Paulen, M. Mojto, C. E. Valero) The quality of the results of model-based optimization and control strongly depends on the accuracy of the models employed. It is essential that the predictions of variables that are considered in the optimization problem, e.g. product quality parameters, are accurate. The quality of the models can be improved by online adaptation of crucial parameters via robust state and parameter estimation schemes. In this respect, we pursue a guaranteed parameter estimation approach to obtain robust estimates of uncertain parameters while avoiding unreliable approximations that are associated with classical estimation approaches.

Distributed and Decentralized Optimization (M. Kvasnica, K. Fedorová, R. Kohút, K. Kiš) Research is focused on the control of the system in distributed and decentralized way, in order to decrease computational burden per calculation unit or increase privacy of each node in network. This approach can be also helpful to find the global optimum of non-convex optimization problems.

6.2 International Scientific Projects

6.2.1 Embedded Optimal Control (M. Fikar)

Period: 2017 – 2022

Partners:

- Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Department of Inform. Eng. and Process Control (research group of M. Fikar)
- Ruhr-Universität Bochum, Department of Automatic Control and Systems Theory, Faculty of Mechanical Engineering (research group of M. Mönnigmann)

The aim of the project supported by the Alexander von Humboldt Foundation is to establish research cooperation between the group of prof. M. Fikar, DrSc at Institute of Information Technology, Automation and Mathematics, Faculty of Food and Chemical Technology of the Slovak University of Technology (STU) in Bratislava (Slovakia) and the group of prof. Dr. M. Mönnigmann at Department of Automatic Control and Systems Theory, Faculty of Mechanical Engineering of the Ruhr-Universität Bochum (RUB). The cooperation will be focused on optimal model-based control and optimisation primarily targeted at embedded control systems. The group at STU is particularly strong at geometric techniques in explicit model predictive control (MPC) and in software development whereas the group at RUB excells in complexity reduction techniques of both explicit and on-line MPC. The main research idea of the project is to take advantage of the interdisciplinary communication and collaboration between specialists from both groups, foster new cooperation activities, and common European research projects. The project includes short-term visits mainly of young scientists from both groups, organisation as well as participation in conferences and lectures at partner groups.

6.2.2 APVV-20-0261: Energy-efficient Safe and Secure Process Control (M. Kvasnica)

Period: 2021 – 2024

The main aim of the project is to develop a systematic and universal design procedure that will yield safe and secure control systems in new applications (so-called greenfield setups), as well as for existing setups (so-called retrofits). This will open the door to industrial applications that will benefit from most progressive techniques for improving the safety, security, and economic performance in process industries.

6.2.3 APVV SK-FR-2019-0004: Fr-Sk Cooperation: Optimal design and control of processes (R. Paulen)

Period: 2020 – 2022

Partners:

- Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Department of Inform. Eng. and Process Control (R. Paulen, M. Fikar, C. Valero, M. Mojto)
- Institut National Polytechnique de Lorraine (INPL) – Ecole Nationale Supérieure des Industries Chimiques (ENSIC) (M. A. Latifi, F. Lesage, Alexis Courtais, Fatima Mtamoros Marin)

The goal of this project is to enhance the cooperation of scientists who share common research interests in the development and application of advanced algorithms for design and control algorithms for dynamic systems in order to achieve greater energy- and material efficiency as well as safety of chemical production sites. The research team consists of students and professors with backgrounds in mathematics, process control and engineering. The scientific goals of the cooperation are to develop methodologies for shape optimization of production plants, effective parameter and state estimation of nonlinear dynamic systems, and techniques of optimal control. Software implementations will be delivered as a part of this project. Moreover, this project aims at a demonstration of the developed tools by applying them to laboratory chemical process systems, membrane filtration system and distillation column.

6.2.4 APVV DS-FR-19-0031: Full-Authority Vehicle Control Strategy (M. Klaučo)

Period: 2020 – 2021

Partners:

- Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Department of Information Engineering and Process Control (M. Klaučo, M. Kvasnica, K. Kiš)
- Czech Technical University, Faculty of Electrical Engineering, Department of Control Engineering (group of Dr. T. Haniš)
- Vienna University of Technology, Division of Control & Process Automation, (group of doc. A. Schirrer)

Joining their research backgrounds, the three involved research institutes will collaborate and exchange on developing and applying nonlinear optimal control methods (nonlinear model-predictive control formulations, estimation problems, parameter identification problems) to industrial application settings in the area of vehicle dynamics. Control tasks that have not been feasible before (e.g., highly-integrated nonlinear drive train optimization) seem feasible by extending and applying nonlinear explicit model-predictive control tools. When successful, these tools allow complex, nonlinear, constraint optimal control to be computed fast enough for realtime control on cheap hardware.

6.2.5 KA107 – Mobility of students and university employees between program countries and partner countries (STU – Thailand) (R. Paulen)

Period: 2020 – 2023

The goal of the project is to mutually reinforce teaching and research activities between the partners STU and Chulalongkorn University (Bangkok, Thailand) in the area of chemical engineering and process control. This goal will be reached by student, research, and academic mobilities that will result in development of research potential of partners and in an increase of students' and employees' qualification. Chulalongkorn University (CU) is the best thai technical university in the long term. Its history counts more than 100 years. During this time, CU made it to be among the top 50 universities in Asia. It is ranked at 247th place in QS University Rankings.

6.3 Research Projects in Slovak Republic

6.3.1 VEGA 1/0691/21: Efficient control of industrial plants using data (R. Paulen)

Period: 2021 – 2024

The project is focused in driving the industrial chemical plants towards effective use of resources and energy. Effective plant management will be reached as a synergy of tools for production planning and for advanced automatic feedback control. The technology enabling the reaching of these goals is based on the use of data a) for creation of input-output data-based models or of first-principles models with corrective data-based terms and b) for reliable monitoring of unmeasured process variables. The improved mathematical models are subsequently used for optimization of steady-state operating regimes and for optimization-based control of industrial plants. The designed algorithms and control structures are tested in simulations as well as in laboratory conditions. The project also stimulates cooperation with industry.

6.3.2 VEGA 1/0585/19: On-Line Tunable Explicit Model Predictive Control for Systems with a Fast Dynamics (M. Kvasnica)

Period: 2019 – 2022

The aim of the project is the development of a unified methodology for the design, synthesis, and implementation of explicit model predictive controllers that can be tuned on-line by changing the parameters of the cost function and/or of the prediction model. Explicit predictive controllers are known to combine quality and safety of nonlinear control algorithms with the cheap implementation complexity known from linear controllers. Therefore they allow for an optimal and safe regulation of systems with a fast dynamics with time constants in the order of milli- to micro-seconds. Their main drawback, however, is that they cannot be re-tuned on-line. Mitigation of this drawback will lead to extension of the current knowledge in the areas of optimal and predictive control and, more importantly, will enable such controllers to be employed in process automation where quality and safety of control algorithms is of paramount importance.

6.3.3 VEGA 1/0545/20: Advanced Control of Energy Intensive Processes with Uncertainties in Chemical, Biochemical and Food Technologies (M. Bakošová)

Period: 2020 – 2023

The research project deals with the development of advanced control methods and algorithms for systems with uncertainties whose implementation will provide significant energy savings in control of energy intensive processes in chemical, biochemical and food technologies. The core of the project is the development of methods and design of algorithms for predictive control, robust predictive control and fuzzy control of systems with uncertainty. Computational efficiency and feasibility in practice will be taken into account when designing control algorithms. Designed control algorithms, controllers, and control structures will be tested by simulations and experiments in laboratory conditions and will be compared according to energy consumption with conventional control approaches. The controlled processes will be chemical reactors, biochemical reactors, heat exchangers, distillation columns and other energy intensive processes typical for chemical, biochemical and food technologies.

6.3.4 Safe process control focused on energy and cost savings (M. Horváthová)

Period: 2020 – 2021

Heat exchangers and chemical reactors are present in almost every industrial production.At present, the control of heat exchangers and chemical reactors does not meet energy standards of the 21st century.Therefore, of the areaswith a high potential for energy savings in industry, is the design of optimal and safe control of heat exchangers and chemical reactors. The main goal of this project is to derive, apply and analyze effective advanced methods to control these energy-intensive processes with regard to safety, energy savings and costs. These advanced control methods will be based on convex optimization. Another goal is to reduce computational complexity over conventional advanced control methods, to increase their applicability in industry. When applied, these new advanced methods will bring significant energy and cost savings. Energy efficiency is a key role in achieving greater objectives, including a healthy economy and sustainable industrial development. Minimizing energy waste is a fundamental pillar in achieving these objectives. Reducing the energy consumption of a technological process also results in a reduction of negative impacts on the environment.

6.3.5 Construction of a Smart Eco Greenhouse VESNA (J. Oravec)

Period: 2021 – 2023

The project significantly contributes to increasing the quality of the teaching process in the field of automation and process control, network communication, and software design. In the theoretical area, the project delivers current international scientific knowledge in the field of automation and process control. The project emphasizes environmental and social responsibility, introduces the current needs of practice into the educational process and increases the skills needed for the successful carriers of graduates. At the same time, the project extends the educational process with modern approaches of teamwork, significantly develops soft skills, and supports the professional growth of students and teachers.

Funding: Tatra bank fund

6.3.6 Design and Implementation of control algorithms for plants in chemical industry (M. Horváthová)

Period: 2021 – 2022

With the growing need for ecologically and economically acceptable solutions, industrial plants are developing and adjusting. In addition, the ongoing COVID19 pandemic has shown us the disadvantages of the need for a human factor in the plants in every part of the industry and the impact of staff shortfalls on the plant. In this context, the further development of automation in all industries has great potential. This project deals with the development and laboratory implementation of control algorithms for plants in the chemical industry. Specifically, heat exchangers and chemical reactors, which are located in most of the factories of the chemical industry. Optimal and safe management of these plants is a key indicator of the energy and economic efficiency of their operation. The main goal of this project is to analyse, modify or propose approaches to control the typical plants of the chemical industry. Subsequently, the proposed approaches, based on models and convex optimization, are validated using a laboratory heat exchanger and a chemical reactor. They are validated in order to ensure a wider industrial implementation of these approaches capable of guaranteeing safety and pursuing the economic and environmental goals of the chemical operation.

6.3.7 Design of Optimal Controllers for Industrial Microprocessors (M. Horváthová)

Period: 2021 – 2023

This project deals with the design and implementation of advanced control methods on embedded microprocessor platforms used in the industry. In order to explore the possibilities of wider industrial implementation of the given advanced control methods. The methods are based on optimization and are able to certify the safety of the operation. Furthermore, the given methods can take into account the requirements for control performance and constraints for controlled and manipulated variables, which leads to an increase in the quality of production, and to a reduction in operating costs and negative impacts on the environment. The implementation of the given methods on embedded platforms is also in accordance with the concept of Industry 4.0. Selected advanced control methods implementable on embedded microprocessor platforms are:

- robust control based on convex lifting
- explicit model predictive control
- predictive control based on neural networks

The control performance of the given methods will be analysed and compared by means of various laboratory equipment, considering the embedded platforms. Selected equipment is:

- laboratory plate heat exchanger
- laboratory chemical reactor
- laboratory air conditioning-heating unit (from the English heating, ventilation, and air conditioning HVAC system)

These plants represent important parts of operations from various industries from chemical and pharmaceutical to manufacturing industry. And the implementation of advanced control methods considering embedded platforms would have the potential to significantly contribute to the development of the industrial operation.

6.3.8 Complexity reduction of explicit model predictive control of plants in chemical industry (L. Galčíková)

Period: 2021 – 2022

Model predictive control is increasingly used in industry due to its many benefits. The main characteristic is the possibility to implement an optimal value of the control action in each control step. Another important feature is the ability to include constraints on controlled and manipulated variables, which is important in the context of plants in the chemical industry. In this way, process limitations, safety, and stability of the control can be observed. Model predictive control also offers the possibility to increase the control performance, or save energy and consumption of the control action. Due to the wide use of the model predictive control, its modification was introduced – explicit model predictive control, which recalculates the optimization problem in advance for the whole set of admissible values, most often the states. This allows explicit model predictive control to be implemented in practice when powerful computing units are not available. However, explicit model predictive control also has the disadvantage of being memory intensive. In addition, if the optimization problem is very complex (the system has many states, inputs, or it is necessary to predict the behaviour of the system for a large number of steps in advance), it also brings challenges for the computational unit. The aim of this project is to reduce the complexity of explicit model predictive control, which allows the implementation on a much larger scale. The first step is to find a method that simplifies the solution of explicit model predictive control. Another task is to validate the proposed method of reducing complexity by simulation or experiment.

6.4 Operating programs

6.4.1 HRS4R 003STU-2-1/2021: Acquisition of the HR Excellence in Research Award – HRS4R na STU (J. Oravec)

Period: 2021 – 2023

The implementation of the project will help STU to obtain the HR Excellence in Research Award and eliminate weaknesses identified by GAP analysis with regard to improving working conditions and professional development opportunities for researchers, creating more attractive conditions for researchers to stay in or new ones decided for STU.
In this project, UIAM solves particular tasks focused primarily on increasing

the quality of e-learning support, including further development and updating e-learning courses, increasing soft skills, and upskilling of students and teachers.

6.4.2 EU-COVID-2021: Research in SMART Monitoring and Disease Prevention Against Coronavirus (SARS-CoV-2) (M. Klaučo)

Period: 2021 – 2023

The project is primarily focused on the development of a SMART system capable of detecting the possible return or outbreaks of COVID-19 in the population of the Slovak Republic based on wastewater analysis (the possibilities of the most accurate determination of outbreaks in individual cities will also be explored). In the next part, the project focuses on the development of micro-sensors designed for rapid detection of the virus (in wastewater and also in biological samples (saliva, skin or urine) in potentially infected.The project also focuses on the development and testing of innovative degradation and decontamination procedures and technologies (development of treatment technology, especially wastewater from point sources such as medical facilities, technologies modifying the process of drinking water treatment, antiviral materials based on selected polymers and modification of nanofibers to produce protective suits) capable of preventively protecting not only the civilian population but also technology or equipment using state security forces (decontamination of statutes or technology based on non-chlorinated oxidizing agents). In the framework of water purification and decontamination, new types of sorption materials based on carbon and silicon, selected nanomaterials and their modifications, membrane technologies and green oxidizing agents or their possible combinations will be investigated.

7 Cooperations

7.1 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)
- Automatic Control Laboratory, ETH Zurich, Switzerland (Model Predictive Control, Modeling, analysis, and control of hybrid systems)
- University of Bochum, Bochum, Germany (Closed-loop identification, Model Predictive Control)
- University of Dortmund, Dortmund, Germany (Model Predictive Control)
- Technical University of Budapest, Budapest, Hungary (Modelling of chemical processes)
- University of Veszprem, Hungary (Environmental engineering, Bioengineering projects)
- TU Wien, Austria (Optimal control and estimation)
- Imperial College London, London, United Kingdom (Global optimization, Parameter estimation)
- Institute of Automatic Control, Faculty of Automatic Control, Electronics and Computer Science, Silesian University of Technology, Gliwice, Poland (Modelling and control of heat exchangers)
- Department of Mechanical System Engineering, Faculty of Engineering, Shinshu University, Nagano, Japan (Modelling and control of the plants with quantized inputs)

7.2 Cooperations in Slovakia

- Institute of Robotics ans Cybernetics, Institute of Automotive Mechatronics, 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 Informatics, Slovak Academy of Sciences, Bratislava
- Department of Cybernetics and Artificial Intelligence, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Košice
- Institute of Control and Informatization of Production Processes, BERG Faculty, Technical University of Košice, Košice
- ProCS s.r.o, Actemium Slovakia, Šaľa
- Slovnaft, Inc., Bratislava
- NCHZ, Inc., Nováky
- Repar building control s.r.o., Bratislava
- TESLA Blue Planet s. r. o., Liptovský Hrádok

7.3 Membership in International Organizations and Societies

- International Federation of Automatic Control, Laxenburg, Austria (M. Fikar, M. Klaučo, R. Paulen)
- European Federation of Biotechnology, Brussels, Belgium (A. Mészáros)
- New York Academy of Sciences, New York, USA (A. Mészáros)
- European Control Association (R. Paulen)
- IEEE (M. Fikar, M. Klaučo)
- European Federation of Chemical Engineers, working party on CAPE (M. Fikar, A. Mészáros)
- Czech Society of Chemical Engineering(M. Bakošová)

7.4 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, J. Mikleš, A. Mészáros)
- Slovak Society of Industrial Chemistry

8 Theses and Dissertations

8.1 Bachelor Theses (B.Sc. degree)

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

M. Bujdáková	Design and implementation of control algorithms on an 8-bit microprocessor (Kvasnica, M.)
M. Meliška	Identification of elevated temperature of persons. Testing with a low-budget thermal imager (Valo, R.)
T. Mészárosová	Modeling of laboratory distillation column in gPROMS ModelBuilder (Paulen, R.)
M. Špaková	Construction and programming of a robotic vehicle with omnidirectional wheels (Valo, R.)
T. Turčan	Modeling and control of fermentation reactor (Klaučo, M.)
P. Valábek	Touchless control of device through hand gestures (Klaučo, M.)
J. Vargan	Indoor air quality monitoring (Klaučo, M.)

8.2 Master Theses (M.Sc. degree)

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

M. Bachorík	Synthesis of a digital twin for a chemical reactor through machine learning (Klaučo, M.)
D. Dzurková	Design and Development of a Human-operated Remote Robotic Manipulator (Kalúz, M.)
M. Gömöry	Modelling and optimal operation of a laboratory membrane separation (Paulen, R.)
M. Gubrický	Application of integer programming for creating optimal schedules (Klaučo, M.)
S. Hrstka	Automatic Detection of Activation of Energy Loads (Kvasnica, M.)
K. Karaffová	Analysis of carbon footprint generated by advanced control of heat exchanger (Oravec, J.)
J. Kavor	PLC-based Processes Control and Visualization (Kalúz, M.)
D. Križan	Software sensors for industry (Paulen, R.)
M. Mateáš	Optimal dynamic experiment design (Paulen, R.)
L. Míková	Move-Blocking-Based Model Predictive Control Design for Laboratory Chemical Reactor (Oravec, J.)
D. Ondra	Creating a responsive web-based scheduling system (Klaučo, M.)
P. Szedlák	Design and implementation of mobile applications (Čirka, Ľ.)
J. Štofa	Design and Implementation of the Chemical Papers Web Portal (Čirka, Ľ.)

Z. Vagaská — Sensing system for identification of color objects for sorting purposes
(Kalúz, M.)

8.3 Dissertations (PhD. degree)

P. Bakaráč — Model Predictive Control for Systems with Fast Dynamics
(Kvasnica, M.)

9 Publications

9.1 Articles in Journals

1. L. Galčíková – J. Oravec: Fixed complexity solution of partial explicit MPC. *Computers & Chemical Engineering*, pp. 1 – 8, 2021. doi: https://doi.org/10.1016/j.compchemeng.2021.107606

2. A. R. Gottu Mukkula – M. Mateáš – M. Fikar – R. Paulen: Robust multi-stage model-based design of optimal experiments for nonlinear estimation. *Computers & Chemical Engineering*, pp. 107499, 2021. doi: https://doi.org/10.1016/j.compchemeng.2021.107499

3. M. Horváthová – J. Oravec – M. Bakošová – A. Mészáros: Carbon Footprint Analysis of a Laboratory Plate Heat Exchanger Control. *Chemical Engineering Transactions*, pp. 847 – 852, 2021. doi: https://doi.org/10.3303/CET2188141

4. M. Horváthová – J. Oravec – M. Bakošová – A. Mészáros: Carbon Footprint Analysis of a Laboratory Plate Heat Exchanger Control. *Chemical Engineering Transactions*, pp. 847 – 852, 2021. doi: https://doi.org/10.3303/CET2188141

5. Y. Jiang – J. Oravec – B. Houska – M. Kvasnica: Parallel MPC for Linear Systems with Input Constraints. *IEEE Transactions on Automatic Control*, pp. 3401 – 3408, 2021. doi: https://doi.org/10.1109/TAC.2020.3020827

6. M. Mojto – M. Horváthová – K. Kiš – M. Furka – M. Bakošová: Predictive control of a cascade of biochemical reactors. *Acta Chimica Slovaca*, pp. 51 – 59, 2021. doi: https://doi.org/DOI:10.2478/acs-2021-0007

7. M. Mojto – K. Ľubušký – M. Fikar – R. Paulen: Data-based design of inferential sensors for petrochemical industry. *Computers & Chemical Engineering*, pp. 107437, 2021. doi: https://doi.org/10.1016/j.compchemeng.2021.107437

8. J. Oravec – M. Horváthová – M. Bakošová: Multivariable Robust MPC Design for Neutralization Plant: Experimental Analysis. *European Journal of Control*, pp. 289 – 300, 2021. doi: https://doi.org/10.1016/j.ejcon.2020.07.012

9. S. Subramanian – S. Lucia – R. Paulen – S. Engell: Tube-enhanced multi-stage model predictive control for flexible robust control of constrained linear systems with additive and parametric uncertainties. *International Journal of Robust and Nonlinear Control*, pp. 4458 – 4487, 2021. doi: https://doi.org/10.1002/rnc.5486

10. A. Vasičkaninová – M. Bakošová – A. Mészáros: Fuzzy Control Design for Energy Efficient Heat Exchanger Network. *Chemical Engineering Transactions*, pp. 529 – 534, 2021. doi: https://doi.org/0.3303/CET2188088

9.2 Articles in Conference Proceedings

1. A. Ahmad – R. Paulen – R. Valo – M. Fikar – S. Engell: Experimental validation of iterative real-time optimization for a continuously operated membrane separation pilot plant. In *ECCE 13 & ECAB 6 – 13th European Congress of Chemical Engineering & 6th European Congress of Applied Biotechnology – Book of Abstracts*, DECHEMA e.V., pp. 499 – 500, 2021. https://doi.org/10.1016/j.ifacol.2020.12.687

2. R. Dyrska – R. Mitze – M. Fikar – M. Kvasnica – M. Mönnigmann: Skipping Optimization Problems in Nonlinear Model Predictive Control by Exploiting Saturation. Editor(s): R. Paulen, M. Fikar and J. Oravec, In *Proceedings of the 23rd International Conference on Process Control – Summaries Volume*, Slovak Chemical Library, Slovak University of Technology in Bratislava, Radlinského 9, SK812-37, Bratislava, Slovakia, pp. 48 – 48, 2021.

3. D. Efremov – T. Haniš – M. Klaučo: Haptic Driver Guidance for Lateral Driving Envelope Protection Using Model Predictive Control. In *IEEE Intelligent Vehicles Symposium*, IEEE Xplore, Las Vegas, NV, USA, USA, 2021. doi: https://doi.org/10.1109/IV47402.2020.9304663

4. K. Fedorová – R. Kohút – M. Kvasnica: Streamlining Active Set Method in MPC using Cache Memory. In *Preprints of the 7th IFAC Conference on Nonlinear Model Predictive Control*, IFAC-PapersOnLine, Bratislava, Slovakia, no. 6, vol. 54, 2021. doi: https://doi.org/10.1016/j.ifacol.2021.08.543

5. M. Fikar – M. Furka – M. Horváthová – K. Kiš – M. Mojto: Dynamic Optimisation Toolbox dynopt 5.0. Editor(s): R. Paulen and M. Fikar, In *Proceedings of the 23rd International Conference on Process Control*,

IEEE, Slovak University of Technology, pp. 296 – 301, 2021. doi: https://doi.org/10.1109/PC52310.2021.9447520

6. M. Furka – K. Kiš – P. Bakaráč – M. Klaučo: Nonlinear MPC Policy for Systems with Data Driven Identification. In *Proceedings of the 7th IFAC Conference on Nonlinear Model Predictive Control*, IFAC-PapersOnline, no. 54, 2021.

7. M. Furka – K. Kiš – M. Klaučo – M. Kvasnica: Usage of Homomorphic Encryption Algorithms in Process Control. Editor(s): R. Paulen and M. Fikar, In *Proceedings of the 23rd International Conference on Process Control*, IEEE, Slovak University of Technology, pp. 43 – 48, 2021. doi: https://doi.org/10.1109/PC52310.2021.9447536

8. M. Horváthová – N. Ishihara – J. Oravec – Y. Chida: Robust Setpoint Tracking of a Linear System with Discrete Actuators. Editor(s): R. Paulen and M. Fikar, In *Proceedings of the 23rd International Conference on Process Control*, IEEE, Slovak University of Technology, pp. 229 – 236, 2021. doi: https://doi.org/10.1109/PC52310.2021.9447482

9. K. Kiš – M. Klaučo – M. Kvasnica: Explicit MPC in the form of Sparse Neural Networks. Editor(s): R. Paulen and M. Fikar, In *Proceedings of the 23rd International Conference on Process Control*, IEEE, Slovak University of Technology, pp. 163 – 168, 2021. doi: https://doi.org/10.1109/PC52310.2021.9447528

10. R. Kohút – L. Galčíková – K. Fedorová – T. Ábelová – M. Bakošová – M. Kvasnica: Hidden Markov Model-based Warm-start of Active Set Method in Model Predictive Control. Editor(s): R. Paulen and M. Fikar, In *Proceedings of the 23rd International Conference on Process Control*, IEEE, Slovak University of Technology, 2021.

11. M. Mateáš – R. Paulen: Optimal Experiments via Sequential and Two-stage Designs. Editor(s): R. Paulen, M. Fikar and J. Oravec, In *Proceedings of the 23rd International Conference on Process Control – Summaries Volume*, Slovak Chemical Library, Slovak University of Technology in Bratislava, Radlinského 9, SK812-37, Bratislava, Slovakia, pp. 47 – 47, 2021.

12. M. Mojto – K. Ľubušký – M. Fikar – R. Paulen: Data Treatment of Industrial Measurements: From Online to Inferential Sensors. Editor(s): R. Paulen, M. Fikar and J. Oravec, In *Proceedings of the 23rd*

International Conference on Process Control – Summaries Volume, Slovak Chemical Library, Slovak University of Technology in Bratislava, Radlinského 9, SK812-37, Bratislava, Slovakia, pp. 52 – 53, 2021.

13. M. Mojto – K. Ľubušký – M. Fikar – R. Paulen: Data-based Industrial Soft-sensor Design via Optimal Subset Selection. Editor(s): Metin Türkay, Rafiqul Gani, In *31st European Symposium on Computer Aided Process Engineering*, Elsevier, vol. 31, pp. 1247 – 1252, 2021. doi: https://doi.org/10.1016/B978-0-323-88506-5.50192-3

14. C. E. Valero – M. Bakošová: Classic Methodologies in Control of a Yeast Fermentation Bioreactor. Editor(s): R. Paulen and M. Fikar, In *Proceedings of the 23rd International Conference on Process Control*, IEEE, Slovak University of Technology, 2021. doi: https://doi.org/10.1109/PC52310.2021.9447543

15. P. Valiauga – X. Feng – M. Villanueva – R. Paulen – B. Houska: Set-membership Estimation using Ellipsoidal Ensembles. Editor(s): Jong Min Lee, In *16th IFAC Symposium on Advanced Control of Chemical Processes ADCHEM 2021*, Elsevier, pp. 596 – 601, 2021. doi: https://doi.org/10.1016/j.ifacol.2021.08.307

16. A. Vasičkaninová – M. Bakošová – A. Mészáros: Control of Heat Exchangers in Series Using Neural Networks. Editor(s): R. Paulen and M. Fikar, In *Proceedings of the 23rd International Conference on Process Control*, IEEE, Slovak University of Technology, pp. 237 – 242, 2021. doi: https://doi.org/10.1109/PC52310.2021.9447484

17. MSc. Carlos E. Valero – R. Paulen: Set-membership State Estimation for a Continuous Stirred-Tank Reactor. In *ICSC – 9th International Conference on Systems and Control*, Caen, France.

9.3 Other

1. M. Bakošová — A. Vasičkaninová: Neural Network-based Innovative Control of a Fermentation Process. Keynote Lecture at the 5th Sustainable Process Integration Laboratory Scientific Conference: Energy, Water, Emission & Waste Industry and Cities, Brno 2021.

10 International Visits

10.1 Visits at our Department

- 2.–26.11.2021 D. Efremov FEE CTU Prague

10.2 Visits from our Department

Participation at Conferences

- 1–4.6.2021 M. Bakošová, M. Fikar, M. Furka, K. Kiš, R. Kohút, M. Mojto, Carlos E. Valero — IEEE 23rd International Conference on Process Control, The High Tatras, Slovakia
- 6.–9.6.2021 M. Mojto — The 31st European Symposium on Computer Aided Process Engineering, Istanbul, Turkey
- 13.–16.6.2021 R. Paulen — 11th IFAC International Symposium on Advanced Control of Chemical Processes, Venice, Italy
- 11.–14.7.2021 K. Fedorová, M. Furka — 7th IFAC Conference on Nonlinear Model Predictive Control 2021, Bratislava, Slovakia
- 24.–26.9.2021 Carlos E. Valero — 9th International Conference on Systems and Control, Caen, France

Research Visits

- 17.–23.10.2021 M.Mojto, R. Paulen — ENSIC, Université de Lorraine, Nancy, France
- 15-19.11.2021 D. Dzurková — EIT Manufacturing Doctoral School (online)
- 22-26.11.2021 D. Dzurková — EIT Manufacturing Doctoral School, Porto, Portugal

Erasmus

- 9.-12.2021 Carlos E. Valero — Bourges-France

11 Miscellaneous

11.1 Organisation of International Conferences

- IEEE 23rd International Conference on Process Control (NOC: M. Klauco, J. Oravec, IPC: R. Paulen, M. Fikar)

- 7th IFAC Conference on Nonlinear Model Predictive Control 2021 (July 11-14) (NOC: M. Kvasnica, M. Klauco)

11.2 Awards

- doc. Ing. Monika Bakošová, CSc.

  - Certificate of Excellence as a Keynote Speaker at the 5th Sustainable Process Integration Laboratory Scientific Conference: Energy, Water, Emission & Waste Industry and Cities, Brno 2021

- doc. Ing. Juraj Oravec, PhD.

  - Teacher of the year 2020 : On the occasion of Teachers' Day, Dean of the FCHPT STU in Bratislava, Prof. Anton Gatial, awarded the Teacher of the Year 2020 Award which was won by Assoc. Prof. Juraj Oravec. In addition to the best ratings in teaching, he is devoted to promotion and science popularization activities.

- Ing. D. Dzurková

  - ACTEMIUM award for the outstanding master thesis

- Ing. L. Galčíková

  - Dean's Prize at the Slovak University of Technology for significant extracurricular activities and excellent study results

- Ing. M. Horváthová

  - Dean's Prize at the Slovak University of Technology for significant extracurricular activities and excellent study results

11.3 Scholarship

- MSc. Carlos E. Valero
  - 1.– 6.2021 DAAD Germany at the Technical University of Munich (TUM)