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FACULTY OF CHEMICAL AND FOOD TECHNOLOGY
INSTITUTE OF INFORMATION ENGINEERING, AUTOMATION
AND MATHEMATICS

DEPARTMENT OF INFORMATION
ENGINEERING AND PROCESS CONTROL

ANNUAL REPORT

2007

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I 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 forty-year tradition. In the frame of the study branch Chemical Engineering and Process Control on the specialization Process Control, it educates high-qualified specialists in the field of process control for design, implementation and processing of control systems.

Nowadays, information technologies and process control with using microprocessor based control technique represent important and acknowledged scientific branches. These branches more and more influence the economic and social growth in the whole world and successively also in our country. The chemical, food and pharmaceutical industries with their technologies are no exceptions. No technology is able to be successful in the competition without optimisation 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 modelling 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 Internet programming.

Prof. Dr. Ing. Miroslav Fikar

II 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 1 January – 31 December 2007.

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 three 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, PhD, DSc in 1962 – 1986. Prof. Ján Mikleš, PhD, DSc headed the department in 1986 – 1994 and in 1998 – 2003. The head in 1995 – 1997 was Assoc. Prof. Alojz Mészáros, PhD and Prof. Dr. Ing. Miroslav Fikar has headed the department since 2003.

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

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IV TEACHING AND RESEARCH LABORATORIES

IV.1 Teaching Laboratories

Laboratory of Process Control
Laboratory of Control Systems
Laboratory of Measuring Instruments and Techniques
Computer Laboratory (PC - Windows, Linux)
Computer Laboratory (Solaris)

IV.2 Research Laboratories

Laboratory of Control Theory
Laboratory of Modelling and Simulation
Laboratory of Identification
Laboratory of Optimisation

Laboratory of Neural Networks
 Laboratory of Fuzzy Control and Expert Systems
 Laboratory of Chemical Reactor Analysis and Control
 Laboratory of Biochemical Process Analysis and Control
 Laboratory of Distillation Column Analysis and Control
 Laboratory of Computer Aided Design (Siemens-SIMATIC S-7 300,
 FOXBORO, Yokogawa)

V. EDUCATIONAL ACTIVITIES

V.1 Bachelor Study

1st semester (autumn)

Informatics	1/0/2	Blahová, Čížniar, Hirmajer, Podmajerský, Vasičkaninová, Závacká,
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2nd semester (spring)

Computer Based Data Processing	0/0/2	Čirka, Karšaiová, Vaneková
Optimisation	3/3/0	Dvoran, Hirmajer, Líška, Vasičkaninová

4nd semester (spring)

Operating Systems	1/2/0	Fikar, Herceg
Modelling	2/3/0	Bakošová, Karšaiová, Vasičkaninová, Závacká

5th semester (autumn)

Computer Based Data Processing	0/0/2	Vasičkaninová
Process Control	2/0/0	Bakošová
Laboratory Exercises of Process Control	0/0/2	Bakošová, Karšaiová, Vasičkaninová
Design of control and information systems	2/3/0	Čirka, Kvasnica, Vaneková

6th semester (spring)

Automatic Control Fundamentals	2/0/0	Bakošová, Fikar
Laboratory Exercises of Automatic Control Fundamentals	0/0/2	Bakošová, Karšaiová, Líška, Puna, Vasičkaninová, Závacká
Bachelor projects	0/0/4	Herceg, Hirmajer, Puna, Vaneková

V.2 Master Study

1st semester (autumn)

Process Control	1/0/2	Bakošová, Karšaiová
Process Dynamics	2/0/0	Bakošová
Operating Systems	1/0/1	Fikar
Control Devices and Systems	2/0/1	Kvasnica
Computer Programs	1/0/2	Čirka
Laboratory Project I	0/0/8	Bakošová, Čirka, Čížniar, Karšaiová

2nd semester (spring)

Optimisation	2/0/1	Dvoran
Control Theory I	2/0/2	Čirka, Mikleš
Laboratory Exercises of Control Theory I	0/0/2	Mikleš
Experimental Identification	2/0/0	Fikar
Laboratory Project II	0/0/6	Čirka, Danko, Dvoran, Vaneková
Modelling and Control of Polymerization Processes	2/0/2	Dvoran

3rd semester (autumn)

Control Theory II	2/0/0	Mészáros
Laboratory Exercises of Control Theory II	0/0/2	Mészáros
Intelligent Control Systems	2/0/0	Dvoran
CAD Systems	2/0/0	Karšaiová
Semestral Project	0/0/8	Čirka, Dvoran, Karšaiová, Vaneková
Industrial Applications of Process Control	2/0/0	Vaneková
Control of Technological Processes	1/0/2	Bakošová, Vasičkaninová
Robust Control	2/0/0	Fikar

4th semester (spring)

Diploma Theses	0/0/27	Bakošová, Čirka, Fikar, Mikleš, Vaneková, Vasičkaninová
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V.3 PhD Study

1st semester (autumn)

Control Theory I (Selected topics) 2/0/0 Mikleš

2nd semester (spring)

Control Theory II (Selected topics) 2/0/0 Mikleš

3rd semester (autumn)

Modelling and Control of
Chemical Processes 2/0/0 Bakošová

Identification of
Dynamic Systems 2/0/0 Fikar

Intelligent Control Systems 2/0/0 Dvoran

V.4 Course contents

V.4.1 Lectures in Bachelor study

Informatics (1h/week, 1st semester)

MS Windows XP as an operating system. The programs of the free package (OpenOffice) are used: Writer as a text processor; Calc as a tool for data processing, data processing by tables, data visualization by graphs; and Impress for presentations.

Optimisation (3h/week, 2nd semester)

Static optimisation, classification of problems, goal functions, boundaries. Extremum without boundaries – analytical methods. Single-dimensional case, multi-dimensional case, Hess matrix. Conditions for extremum. Extremum with boundaries – linear boundaries, direct method, method of Lagrange multipliers. Extremum with boundaries – nonlinear boundaries, Kuhn – Tucker theorem. Non-gradient methods – Box-Wilson method, flexible simplex method, method of cyclic exchange of parameters. Gradient methods – Regula falsi method, Newton method, Broyde method, DFP method, PARTAN method. Convergence of gradient methods.

Operating Systems (1h/week, 4st semester)

Introduction to operating systems of computers. Linux – operation system of UNIX-type. Free and Open Source Software, GNU Foundation. Introduction to Solaris operating system. Basic file and directory operations, editing, searching, regular expressions, remote computers.

Design of control and information systems (2h/week, 5th semester)

Main ingredients and classification of control systems. Main goals of control systems. Devices for control and automation. Information technologies, World Wide Web and the XML format for data exchange. Databases and web programming languages. Real-time control issues. Advanced control algorithms, fuzzy control, artificial neural networks, and Model Predictive Control. Safety and security of modern control and information systems.

Automatic Control Fundamentals (2h/week, 6th semester)

Introduction to automatic control fundamentals. Modelling of special types of processes of chemical technology. Static and dynamic behaviour of controlled systems. Closed loop for control of technological processes. Controllers. Dynamic behaviour of closed loops. Stability of systems. Synthesis of controllers. Control of special types of processes of chemical technology. Basic principles of devices and methods for measurement of technological quantities.

V.4.2 *Lectures in Master study*

Process Control (1h/week, 1st semester)

Introduction to process control. Various forms of mathematical description of linear continuous-time systems and their connections. Input-output differential equation, transfer function, frequency-response function, state-space equation and its solution, mathematical description of systems with time delays. Frequency responses of linear continuous-time systems, responses on arbitrary signals. Internal properties of linear continuous-time systems: stability, controllability, observability, properness, stabilisability. Stability of feedback control loops. Controller synthesis. Mathematical models of linear discrete-time systems. Discrete PID controller.

Process Dynamics (2h/week, 1st semester)

Fundamentals of chemical process modelling and simulation. Nonlinear and linearized models of serially connected tanks, the static and dynamic behaviour. Dynamic behaviour of processes with heat exchange: shell heat exchangers with ideal mixing of media, tube heat exchangers, co-current and counter-current cases. Dynamic behaviour of processes with material exchange: plate distillation columns, stuffed distillation columns, stuffed absorption columns. Dynamic behaviour of processes with chemical reactions: continuous-time stirred tank reactors, tube reactors without or with catalyst.

Operating Systems (1h/week, 1st 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.

Control Devices and Systems (2h/week, 1st semester)

Continuous-time controllers, types and their static and dynamic behaviour. Discrete controllers, their dynamic behaviour and using in control loops. PC in the role of a controller. Servo-drives for electric and pneumatic control system. Control valves. Digital devices. Logic functions, electric devices for realization of logic functions. Sequence loops. Hardware for control of technological processes. Analogue input modules, A/D, D/A converters. Digital input modules. Sources of inaccuracies in control loops.

Computer Programs (1h/week, 1st semester)

MATLAB programming language: internal properties, variables, functions, data analysis, data visualization, data storing, programming in MATLAB. Simulink simulation language: simulation schemes, block parameter settings, simulation parameter setting, block libraries, s-functions. MATLAB/Control toolbox: simulation and control of systems. Origin – graphic software, data processing, data visualization, special functions. Word - text processor.

Optimisation (2h/week, 2nd semester)

Static optimisation, classification of problems, goal functions, boundaries. Extremum without boundaries – analytical methods. Single-dimensional case, multi-dimensional case, Hess matrix. Conditions for extremum. Extremum with boundaries – linear boundaries, direct method, method of Lagrange multipliers. Extremum with boundaries – nonlinear boundaries, Kuhn – Tucker theorem. Non-gradient methods – Box-Wilson method, flexible simplex method, method of cyclic exchange of parameters. Gradient methods – Regula falsi method, Newton method, Broyde method, DFP method, PARTAN method. Convergence of gradient methods. Heuristic and learning methods, genetic algorithms. Linear, dynamic, nonlinear programming. Optimal and strategic decision-making. Large-scale optimisation tasks and their decomposition.

Control Theory I (2h/week, 2nd semester)

Continuous-time systems, discrete systems. Pole-placement method. State-space approach. Deterministic state estimate. Dynamic output feedback. Connections between state and input-output approach to control design. Pseudo-state. Asymptotic observer. Control law based on an observer for deterministic problem. Fractional approach, set of all stabilizing controllers. BIBO stability. Parameterisation of stabilizing controllers. Bezaut equation. Dynamic optimisation. Principle of minimum. Fundamental theorem of the variation

calculus. Necessary conditions for the optimal control. LQC problem. Kalman linear (L), quadratic (Q) controller. Euler-Lagrange equations. Optimal control. Matrix Riccati equation. Output control. LQ controller with integral properties. LQ control. Connections between the state-space and input-output approaches. Spectral factorisation. LQ control and deterministic state estimation. Polynomial solution of the problem. PI controllers and LQ controller design. Optimal LQ tracking of SISO systems, input-output approach. State and parameter identification. LQ state controller, LQG input-output controller. H_2 feedback control. Solution by using of two generalized algebraic Riccati equations. Connection between LQG and H_2 control.

Experimental Identification (2h/week, 2nd 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 multivariable and continuous-time systems. Aspects of the least square method and identification of static models, passive and active experiment. Correlation methods of identification, stochastic signals, correlation functions. Wiener-Hopf equation and its using for identification. Filtration and prediction of signals. State estimation and observability – Lueneberg observer, Kalman filtration. Using of identification for modelling and control of technological processes.

Modelling and Control of Polymerization Processes (2h/week, 2nd semester)

Principles of modelling of processes of chemical technology. Analytical and experimental approaches to modelling. Identification of static models based on the least square method. Recursive identification of discrete dynamic models. Analysis of synthesis, modification and production of polymers from the measurement and control point of view. Analysis of fibre production from the measurement and control point of view. Analysis of tire production from the measurement and control point of view. Analysis of processes of polygraphic technology from the control point of view. Analysis of processes of pulp and paper technology from the control point of view.

Control Theory II (2h/week, 3rd semester)

Algebraic theory of linear control, mathematical basement. Using of algebraic theory for continuous-time and discrete controller design, pole-placement, dead beat. Adaptive control. Self-tuning adaptive systems, recursive identification. Continuous-time and discrete adaptive control. Model reference adaptive control

systems (MRAS), principles, MRAS according to MIT, MRAS in the sense of Ljapunov theory of stability. Predictive control. Robust control, H_2 and H_∞ control.

Intelligent Control Systems (2h/week, 3rd semester)

Expert systems – knowledge based systems. Knowledge representation. Basic features of expert systems, structure and processing. Diagnostic expert systems. Planning expert systems. Expert systems based on rules, frames and logical programming. Programming tools for expert systems – programming languages LISP and PROLOG. Fuzzy systems. Basic principles of fuzzy sets and fuzzy logic. Fuzzy decision processes, fuzzy modelling and identification. Design procedures for fuzzy logic controllers. Rule based fuzzy controllers, model based fuzzy controllers. Neural nets. Basic principles of artificial neural nets (ANS). Representation of dynamic systems using feed-forward and feedback neural nets. System identification based on using of neural nets. Parameter estimation and neural net training. Controllers based on using of neural nets. Adaptive control based on using of neural nets, direct and non-direct. Genetic control algorithms. Control of textile production.

CAD Systems (2h/week, 3rd semester)

Classification of automatic control systems, types of control algorithms. Automatic control system design. Feedback control loops – simple, composed. Control loops for flow rate, pressure, level control. Control loops for heat exchangers, distillation, absorption, extraction columns, batch and continuous-time chemical reactors. MIMO control of distillation columns. Large-scale systems – analysis, modelling and control.

Industrial Application of Process Control (2h/week, 3rd semester)

Introduction to industrial application of process control. Problems connected with control system design and control system application in practice. Hardware and software of industrial control systems, programming of industrial automata, data processing and visualization. Control of a chemical reactor for a decomposition of H_2O_2 . Control of a binary plate distillation column. Solving of control problems for chemical industry.

Control of Technological Processes (1h/week, 3rd semester)

The course is given for students of specialization Organic Technology and Petrochemistry. Course content is following. Introduction to control of technological processes. Principles of control of technological processes: feedback and feedforward control. Simple feedback control loop. Methods for PID controller synthesis. Complex control loops: time-delay compensation (Smith predictor), cascade control, feedforward compensation of disturbances, flow-ratio control. Control of tanks, control and controlled variables. Control of

heat exchangers, controlled and control variables, control loops. Control of distillation and absorption columns, controlled and control variables, control loops. Control of chemical reactors, controlled and control variables, control loops. Basic principles of devices and methods for measurement of technological quantities: liquid level, temperature, pressure, flow rate, concentration.

V.4.3 *Laboratory exercises in Bachelor study*

Informatics (2h/week, 1st semester)

MS Windows XP operating system. MS Excel as a tool for data processing, data processing by tables, data visualization by graphs. MS Word – text processor.

Computer Based Data Processing (2h/week, 2nd semester)

MATLAB – Simulink as a tool for system simulation, MATLAB – Control toolbox. Filtration of signals, analogue and digital filters, MATLAB – Signal processing toolbox. MS Excel as a tool for data processing. Data processing by tables, data visualization by graphs, analytical tools in MS Excel, statistics in MS Excel. Origin as a tool for data visualization and processing.

Optimisation (3h/week, 2nd semester)

Extremum without boundaries – analytical methods. Single-dimensional case, multi-dimensional case. Extremum with boundaries – linear boundaries, direct method, method of Lagrange multipliers. Extremum with boundaries – nonlinear boundaries. Non-gradient methods – Box-Wilson method, flexible simplex method, method of cyclic exchange of parameters. Gradient methods – Regula falsi method, Newton method, Broyde method, DFP method, PARTAN method.

Laboratory Exercises of Automatic Control Fundamentals (2h/week, 6th semester)

MATLAB/Simulink as a simulation tool for LEACF. Laplace transform as a mathematical tool for LEACF. Input-output description of dynamic systems, transfer functions, poles and zeros. Step responses and impulse responses of dynamic systems. Mathematical models and dynamic behaviour of processes of chemical technology. Feedback control. PID controllers and their properties in feedback control. Controller synthesis and control of processes of chemical technology.

V.4.4 *Laboratory exercises in Master study*

Laboratory Exercises of Control Theory I (2h/week, 2nd semester)

Simulation of pole-placement method. State-space approach. State observer design for simple systems. Simulation of state feedback. Simulation of feedback control with a state observer. Design of a set of stabilizing controllers for simple systems. Simulation of MIMO feedback systems by using of stabilizing controllers. Simulation of feedback control by using of a LQ controller for simple serially connected tanks and for a chemical reactor. Synthesis of a PI controller, PI controller design by LQ method. Simulation comparison of a classic and a LQ PI controllers. Simulation of LQ control with deterministic state estimation. LQG state controller. Simulation of feedback control by a state-space LQG controller. LQG input-output controller. Adaptive control. Closed-loop identification. Closed-loop recursive identification. Simulation of adaptive control with recursive identification and with LQ/LQG controller. Adaptive control of serially connected tanks, adaptive control of a chemical reactor.

Laboratory Exercises of Process Dynamics (1h/week, 2nd semester)

Simulation of dynamic behaviour of systems in MATLAB/Simulink. Analysis and simulation of static and dynamic behaviour of a system of serially connected tanks with/without interactions. Analysis and simulation of static and dynamic behaviour of a tube heat exchanger as a continuously distributed parameter system. Transformation of a system of partial differential equations to a system of ordinary differential equations by discretization. Calculation of a steady-state of a plate distillation column, analysis and simulation of static and dynamic behaviour of a plate distillation column as a discretely distributed parameter system. Analysis and simulation of static and dynamic properties of an exothermic continuous-time stirred tank reactor. Calculation of steady state of a chemical reactor, steady-state analysis of a chemical reactor, linearization of nonlinear models.

Laboratory Exercises of Control Theory II (2h/week, 3rd semester)

Algebraic theory of linear control. Control of the 2nd order continuous-time system by discrete controller. Self-tuning adaptive control system for the 2nd order linear system, discrete and hybrid approach. Model reference adaptive control (MRAC). Adaptation of static gain. MRAC for the 1st and 2nd order systems. MRAC in the sense of the Ljapunov theory of stability, application on the 1st order system. Predictive control.

VI. 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.

VI.1 Main Research Areas

1. Modelling and Simulation (M. Bakošová, A. Mészáros, J. Mikleš, M. Karšaiová)

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 for PC in Simulink and C-language was created.

2. System Identification (J. Mikleš, M. Fikar, Ľ. Čirka)

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:

- a) nonparametric methods, correlation and spectral analysis
- b) recursive identification of Z-transform discrete-time models
- c) recursive identification of delta models which converge to their continuous-time counterparts
- d) 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.

3. Optimal Control Design (J. Mikleš, M. Fikar, M. Kvasnica)

The main aim of this area is to develop a package of algorithms and program implementation of various known control designs for given plants. The research interests include single input-single output systems as well as multivariable dynamic systems. Control design covers strategies in discrete-time and continuous-time formulation. A program package is created in MATLAB/Simulink environment.

4. Adaptive Controllers (J. Mikleš, M. Bakošová, L. Čírka, M. Fikar)

Most of technological plants exhibit non-linear behaviour. To apply a successful control design to practical problems is a substantial effort. It is known that processes are modelled and controlled with serious difficulties caused by their non-linear behaviour, high order dynamics, and tendency to instability. Many of industrial processes must be considered as multivariable systems. In a great deal of available control design techniques it is often necessary to carry out the steps of modelling, 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 four main areas as follows:

- a) self-tuning control - characterized by repeating parameter estimation and control design
- b) model reference adaptive control based on the Ljapunov method
- c) decentralized adaptive control
- d) adaptive lambda-tracking

5. Neural Networks (A. Mészáros)

The aim of this research is to investigate two-layer hierarchical control structures for biochemical systems, integrated optimising 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.

6. Fuzzy Control and Expert Systems (J. Dvoran, A. Vasičkaninová, P. Líška, L. Blahová)

The aim of this research is to investigate fuzzy and neuro-fuzzy controllers. The usefulness of fuzzy control can be considered in two aspects. First, control offers a novel mechanism to implement such control laws that are often knowledge-based or even in linguistic descriptions. Second, fuzzy control provides an alternative methodology to facilitate the design of nonlinear controllers for such controlled plants that are uncertain and very difficult to cope with conventional nonlinear theory.

7. Predictive Control (M. Fikar, M. Kvasnica, M. Herceg)

The research is focused on predictive control of hybrid systems, i.e. systems that combine continuous dynamics with the aspects of discrete transitions, such as on/off switches or finite state automata. Algorithms,

which provide stability guarantees for such class of systems, are being developed and tested on real devices.

8. Dynamic Optimisation (M. Fikar, M. Kvasnica, M. Čižniar, T. Hirmajer, M. Podmajerský)

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 behaviour of processes. Optimal control theory is able to provide responses to these questions. In this research, changeover problems in multicomponent distillation are studied.

9. Robust Control (J. Mikleš, M. Bakošová, D. Puna, K. Vaneková, J. Závacká)

Robustness has been recognized as a key issue in the analysis and design of control systems for the last two decades. Processing of chemical reactors, heat exchangers, distillation columns, etc. is connected with many different uncertainties. Some of them arise from varying or not exactly known parameters, as e.g. chemical kinetics or reaction activity. In other cases operating points change. The processes are also affecting by various types of perturbations. All these uncertainties can cause poor performance or even instability of closed-loop control system. Application of robust control approach can be one of the possibilities how to overcome all these problems. One of the up to now opened problems is also the problem of a robust static output, which is studied.

10. Process Control

The research of all research groups is focused on control applications for various types of chemical and biochemical processes.

11. Control Engineering Education (M. Fikar, L. Čírka, M. Bakošová, T. Hirmajer)

The research in control engineering education has been oriented on use of new information technologies in control engineering education, interactive on-line courses and automatic generation of test problems. The task of personification of a web page for students and teachers is solved recently.

12. Information Technologies (M. Fikar, L. Čírka, T. Hirmajer, D. Puna)

The research in information technologies has been oriented on
a) use of information technologies for data manipulation, retrieval, and visualization,

b) development of static and dynamic web pages not only for use in control and measurement, but also for general information and data management.

Technologies are based on open-source projects like Apache, MySQL, PHP, etc.

VI.2 Research Projects in Slovak Republic

1. VEGA Project No 1/4055/07: Advanced Approaches to Control of Chemical and Biochemical Processes with Uncertainties (M. Bakošová)

The project deals with development of advanced approaches to control of systems with uncertainties and focuses on processes typical for chemical and food technologies, as e.g. chemical reactors, biochemical reactors, distillation columns, and others. Development of methods of robust analysis, robust stabilization and robust control of systems with uncertainties constitutes the core of the project. Processes with recycle can be also included to the systems with uncertainties. Designed algorithms, controllers, and control structures will be tested by simulations and in laboratory conditions. Obtained results will be transferred to the industrial praxis. The main goals of the project can be listed as follows:

1st phase:

- Bibliography research in the investigated field.
- Connection of laboratory processes to the control system Siemens Simatic S7 300 for the purpose of application of theoretical results.
- Modelling and simulation of systems with uncertainties.
- Identification, modelling and analysis of dynamic behaviour of processes with internal recycle.
- Design of a toolbox of mathematical models of chemical and biochemical processes.
- Development of methods of robust analysis, robust stabilization and robust control of systems with uncertainties.
- Robust stabilization and robust control of chemical and biochemical processes with special attention to chemical reactors, biochemical reactors and distillation columns.
- Design of a software package for robust stabilization and robust control of systems with parametric uncertainties.
- Development of approaches for compensation of recycle effects.
- Development of adaptive and robust control of systems with recycle.

- Adaptive and robust control of systems with recycle with special attention to separation processes and the system chemical reactor – distillation column.
- Design of a software package for adaptive and robust control of systems with recycle.

2nd phase:

- Implementation of the software package for robust stabilization and robust control of systems with uncertainties.
- Implementation of the software package for adaptive and robust control of systems with recycle.
- Intranet connection and remote control of laboratory processes controlled by the Siemens Simatic S7 300 system.
- Application of theoretical results in control of laboratory processes: chemical reactor, biochemical reactor and tray distillation column.
- Transfer of the theoretical and experimental results into industrial conditions and demonstration of the advantages of the modern control methods in Slovak chemical and food industries.

Period: January 2007 – December 2009

2. VEGA Project No 1/3081/06: Optimisation and Control of Chemical and Biochemical Processes (M. Fikar)

The project deals with development of modern control and optimisation methods and focuses into processes typical in chemical and food industries: chemical reactors, distillation columns, waste-water treatment plants, and others. Involves static and dynamic, and global optimisation methods, predictive control as well as supervisory control. Developed algorithms, controllers, and control structures will be tested by simulations and in laboratory conditions. Scientific goals for the first period of this project:

- Bibliography research in the investigated field.
- Connection of laboratory processes to the control systems dSPACE and Siemens.
- Modelling and simulation of hybrid (mixed continuous/discrete) systems.
- Analysis and design of control and optimisation of hybrid systems.
- Dynamic optimisation of a continuous and hybrid processes systems and with special attention to bioreactors and wastewater treatment plants.
- Design of a software package for simulation and dynamic optimisation of hybrid systems.
- Interface of the software package DYNO with MATLAB.

- Global dynamic optimisation – study of existing approaches.
- Design of supervisory control with industrial control systems.
- Design of a software package for multiparametric optimisation and explicit predictive control

Scientific goals for the second period of this project:

- Control design of ASP processes modelled by hybrid models. Comparison and analysis of the results, recommendations for practical implementation of WWTP plants control.
- Implementation of the software package for dynamic optimisation of hybrid systems. Intranet connection and remote control of laboratory processes controlled by the dSPACE and Siemens Simatic S7 300 systems.
- Intranet connection and remote control of laboratory processes controlled by the dSPACE and Siemens Simatic S7 300 systems.
- Application of theoretical results in control and optimisation on the laboratory processes: chemical reactor, distillation columns, heat exchanger, and liquid storage tanks.

Period: January 2006 – December 2008

VI.3 International Scientific Programs

1. Project of French National Science Foundation Polynomial optimisation of complex systems ECO-NET (M. Fikar)

The project investigates the possibility to use the newest results in polynomial methods and linear matrix inequalities developed in LAAS-CNRS Toulouse for solution of various problems: robust control (CTU Prague), control of chaotic systems (ITIA Prague), predictive control (STU Bratislava), nonlinear control (IMPRE, Sankt Peterburg). The cooperation enables to spread the field of applications and the partners become familiar with the latest progress in theoretical and practical aspects of polynomial optimisation.

Participants: Department of Information Engineering and Process Control, FCFT STU, Bratislava, Slovakia; LAAS-CNRS Toulouse, France, CTU Prague, Czech Republic, ITIA Prague, Czech Republic, IMPRE, Sankt Peterburg, Russia

Period: January 2006 – December 2007

2. Project of Slovak – Czech Scientific Cooperation No SK-CZ 11206: Progressive robust and adaptive control methods for processes with heat and mass transfer (M. Bakošová)

The project deals with development of progressive approaches to control of systems with uncertainties and focuses on processes with heat and mass transfer typical for chemical and food technologies, as e.g. distillation columns, heat exchangers, chemical reactors and others. Development of methods of robust analysis, robust stabilization and robust control of systems with uncertainties constitutes the core of the project. Modern adaptive control methods are investigated as well. Designed algorithms and control structures are tested by simulations and on laboratory processes.

Participants: Department of Information Engineering and Process Control, FCFT STU, Bratislava, Slovakia; Faculty of Applied Informatics, Tomas Bata University, Zlín, Czech Republic

Period: January 2006 – December 2007

3. Project of Slovak – Czech Scientific Cooperation No SK-CZ 11106: Advanced control methods for processes of chemical and food technologies (M. Fikar)

The aim of the project is to develop advanced methods for control and optimisation of processes in chemical and food technology, e.g. chemical reactors, distillation columns, sludge processes, etc. Methods of dynamic and global optimisation, predictive control and multistage control design are investigated. Developed control algorithms, controllers and control structures are tested by simulations and in laboratory conditions.

Participants: Department of Information Engineering and Process Control, FCFT STU, Bratislava, Slovakia; Faculty of Technology, University of Pardubice, Pardubice, Czech Republic

Period: January 2006 – December 2007

4. Project of Slovak – Hungarian Scientific Cooperation No SK-MAD-0001-06: Modelling, Optimisation, and Control of Heat and Mass Transfer Processes (M. Fikar)

Partners

- Slovak University of Technology in Bratislava, Faculty of Chemical and Food Technology, Department of Inform. Eng. and Process Control (M. Fikar, M. Bakošová, A. Mészáros, M. Herceg)
- Budapest University of Technology and Economics, Faculty of Chemical Engineering (P. Mizsey, Z. Sztikai, M. Gábor, M. Horváth)

With regard to ongoing research projects at the two partner departments, 3 research areas are selected for future scientific collaboration. They are:

- Chemical Process Modelling and Control
- Integrated Process Design
- Hybrid Separation Process Design

Period: January 2007 – December 2008

VI.4 Educational Projects in Slovak Republic

1. KEGA Project No 3/3121/05: Network of virtual laboratories for control of real systems (M. Fikar)

The aim of the project is to create an open network of virtual laboratories in Slovakia connected together via Internet and to laboratory networks abroad. The project will also implement and test properties of centralised network managed by an educational portal and distributed network created from servers on the participant's laboratories.

Participants: Department of automation and regulation, FEI STU, Bratislava, Assoc. Prof. Huba (coordinator), DIEPC FCHPT STU, Prof. Fikar, Department of Computers and Informatics, FEI TU Košice, Ing. Jakab

Period: January 2005 – December 2007

2. ESF Project No 13120110014: Program of continuing education in industrial automation and information technologies (M. Fikar)

The aim of the project is to realize various courses in industrial automation and information technologies for support of employment.

Participants: DIEPC FCPT STU (coordinator), Prof. Fikar, Department of Automation and Regulation, FEI STU, Assoc. Prof. Huba, Department of Automation and Regulation, Sjf STU, Prof. Rohal'-Il'kiv

Period: January 2005 – December 2007

3. ESF Project No 13120200115: PhD students for modern industrial automation in Slovak Republic (M. Fikar)

Partners:

- Department of Automation, Informatics and Instrumentation, Sjf STU, Assoc. Prof. Belavý (coordinator)
- Department of Information Engineering and Process Control, IIEAM FCPT STU, Assoc. Prof. Fikar

- Institute of Control and Industrial Informatics, FEI STU, Assoc. Prof. Huba

Project aims:

The main aim of the project is to improve quality of employment and competitiveness of Bratislava region via development of education and support of PhD students and young researchers. The project is focused on industrial automation, current and prospective industrial parks and institutions not only in the target region but in the whole Slovakia as well.

Education is targeted to motivation of PhD students in modern automation in automotive, process, biotechnological, and energetical industries. The main aspect is to make possible to study at the most advanced institutions in Europe including not only universities but industries as well.

Period: January 2007 – December 2009

3. ESF Project No 11230220525 and No 13120120287: Preparation of university teachers for ICT in education (M. Fikar)

Partners:

- Institute of Control and Industrial Informatics, FEI STU, Ing. Žáková (coordinator)
- Department of Information Engineering and Process Control, IIEAM FCFT STU, Prof. Fikar
- MtF STU, Assoc. Prof. Schreiber

Project aims:

- To improve quality of university teachers in Slovakia via two mirror projects.
- To provide ECDL certificate of university teachers in presence and distance learning using new elearning technologies so that they will be able to modernise teaching process.
- Later, to provide such possibility to a wider community to improve qualification structure in Slovakia.
- To increase skills of university teachers in e-learning with focus on LMS systems and pedagogical aspects of modern education.
- To create a permanent consultancy services and help desks in ICT.

Period: January 2006 – December 2008

VII. COOPERATION

VII.1 Cooperation in Slovakia

Institute of Control and Industrial Informatics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Bratislava

Institute of Automation, Measurement and Applied Informatics, Faculty of Mechanical Engineering, Slovak University of Technology, Bratislava

Department of Cybernetics and Artificial Intelligence, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Košice

Department of Management and Control Engineering, BERG Faculty, Technical University of Košice, Košice

Siemens, Inc., Bratislava

ProCS, Ltd., Šaľa

Invensys, Inc., Slovakia

VII.2 International Cooperation

Department of Process Control and Computer Techniques, Faculty of Chemical Technology, University of Pardubice, Pardubice, Czech Republic

- Advanced control methods for processes of chemical and food technologies

Department of Computing and Control Engineering, Institute of Chemical Technology, Prague, Czech Republic

- Control of biochemical processes

Faculty of Applied Informatics, Tomas Bata University, Zlín, Czech Republic

- Adaptive control
- Robust control
- Decentralized control

Institute of Information Theory and Automation of the Academy of Sciences of the Czech Republic, Prague, Czech Republic

- Polynomial methods
- Predictive control

Faculty of Electrical Engineering, Czech Technical University, Prague, Czech Republic

- Polynomial methods
- Predictive control

LSGC-CNRS, Ecole Nationale Supérieure des Industries Chimiques (ENSIC), Nancy, France

- Dynamic optimisation of distillation columns
- Waste-water treatment plants

Ecole Nationale Supérieure des Ingénieurs de Génie Chimique-Chemin de la Loge (ENSIGC), Toulouse, France

- Polynomial methods

Ruhr University, Bochum, Germany

- Closed-loop identification
- Predictive control
- E-learning in control

University of Technology and Economics, Budapest, Hungary

- Modelling of chemical processes

VII.3 Membership in Domestic Organizations and Societies

Slovak Society for Cybernetics and Informatics, Bratislava (J. Dvoran, A. Mészáros, J. Mikleš)

Slovak Society of Chemical Engineering (M. Bakošová, J. Dvoran., A. Mészáros, J. Mikleš)

Slovak Society of Industrial Chemistry (M. Bakošová, E. Čirka, J. Danko, L. Dermíšek, J. Dvoran, M. Fikar, M. Karšaiová, A. Mészáros, J. Mikleš, A. Vasičkaninová)

Scientific Grant Agency VEGA MŠSR a SAV - Commission for Elektrotechnics and Informatics (J. Mikleš)

Commission for defence of dissertations (DSc) at science 28-30-9 Chemical Engineering and Process Control (J. Mikleš)

Commission for defence of dissertations (DSc) at science 38-01-9 Automation and Control (J. Mikleš - chairman)

Common branch commission for PhD study at science 28-30-9 Chemical Engineering and Process Control (J. Mikleš – vice-chairman, M. Bakošová, J. Danko, J. Dvoran, M. Fikar, A. Mészáros)

Common branch commission for PhD study at science 38-01-9 Automation and Control (J. Mikleš)

Common branch commission for the field of study 5.2.14 Automation and Control (M. Bakošová, J. Dvoran, M. Fikar, A. Mészáros, J. Mikleš)

Editorial board of AT&P Journal (J. Dvoran, A. Mészáros, J. Mikleš)

Editorial board of Cybernetics and Informatics (J. Mikleš)

VII.4 Membership in International Organizations and Societies

International Federation of Automatic Control, Technical Committee on Control Design (J. Mikleš)

International Federation of Automatic Control (IFAC), Slovak National Member Organization (Slovak NMO) (J. Mikleš)

European Federation of Biotechnology (A. Mészáros)

The New York Academy of Sciences (A. Mészáros)
Public Board of the Hungarian Academy of Sciences (A. Mészáros)
Czech Society of Chemical Engineering (M. Bakošová, A. Mészáros)
EUCA (European Union Control Association) Council (M. Fikar)

VIII. THESES AND DISSERTATIONS

VIII.1 Graduate Theses (Bc Degree)

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

- Briš, M. Control by industrial control system SIMATIC.
(Vaneková, K.)
- Zahradník, M. Control by industrial control system SIMATIC.
(Vaneková, K.)
- Zubček, M. Development of GUI for chemical reactor visualization.
(Puna, D.)
- Schmidt, S. Using of the MPT toolbox in linear optimal control.
(Herceg, M.)

VIII.2 Graduate Theses (MS Degree)

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

- Szúcssová, A. Adaptive network based fuzzy inference systems (ANFIS).
(Vasičkaninová, A.)
- Juhásová, E. A learning unit for a thermofluid process. (Čirka, L.)
- Súkenníková, E. A toolbox for unit testing in MATLAB. (Kvasnica, M.)
- Blaňár, P. Computer Control of Liquid Storage Systems. (Mikleš, J.)
- Madzin, T. Control by industrial control system Foxboro.
(Vaneková, K.)
- Bihuňová, M. Control of time-delay systems (Bakošová, M.)
- Čemanová, L. Development of the GUI for controller synthesis.
(Bakošová, M.)
- Podmajerský, M. Estimation of process parameters from measured data.
(Fikar, M.)
- Doval, P. E-learning Module for Experimental Identification.
(Čirka, L.)
- Vlkanová, J. Fuzzy model predictive control. (Vasičkaninová, A.)
- Mínarovský, P. Implementation of a terminal server in student laboratories.
(Fikar, M.)

- Zábojníková, K. Internet module for process modelling and simulation.
(Bakošová, M.)
- Jančová, K. Robust control of a laboratory process. (Bakošová, M.)

VIII.3 Graduate Theses (PhD Degree)

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

- Hirmajer, T. Dynamic Optimization of Hybrid Processes. (Fikar, M.)

IX. PUBLICATIONS

IX.1 Books

- [1] Huba, M., Bisták, P., Fikar, M.: *Learning Management Systems*, (in Slovak) Slovak e-Academy, Bratislava, 118 pages, 2007.
- [2] Huba, M., Bisták, P., Fikar, M.: *Authors of e-learning*, (in Slovak) Slovak e-Academy, Bratislava, 204 pages, 2007.
- [3] Mikleš, J., Fikar, M.: *Process Modelling, Identification, and Control*, Springer Verlag, Berlin Heidelberg, 2007.
- [4] Fikar, M.: *Dynamic Optimisation of Processes*, (in Slovak) STU Bratislava and Slovak e-Academy, Bratislava, 2007.

IX.2 Chapter or pages in book

- [1] Bakošová, M., Puna, D.: *Selected Topics in Modelling and Control*, Editor(s): Mikleš, J., Veselý, V., Chapter: Control of a Continuous-Time Stirred Tank Reactor via Robust Static Output Feedback. Slovak University of Technology Press, vol. **5**, pp. 38-44, 2007.
- [2] Čirka, L., Fikar, M.: *Selected Topics in Modelling and Control*, Editor(s): Mikleš, J., Veselý, V., Chapter: A Dynamical System Identification Toolbox. Slovak University of Technology Press, vol. **5**, pp. 58-62, 2007.
- [3] Čirka, L., Fikar, M., Mikleš, J.: *Selected Topics in Modelling and Control*, Editor(s): Mikleš, J., Veselý, V., Chapter: Youla–Kučera Parameterisation Approach to LQ Tracking and Disturbance Rejection Problem. Slovak University of Technology Press, vol. **5**, pp. 8-12, 2007.
- [4] Čižniar, M., Fikar, M., Latifi, M. A.: *Selected Topics in Modelling and Control*, Editor(s): Mikleš, J., Veselý, V., Chapter: A Matlab Package for Dynamic Optimisation of Processes. Slovak University of Technology Press, vol. **5**, pp. 52-57, 2007.

- [5] Herceg, M., Fikar, M.: *Selected Topics in Modelling and Control*, Editor(s): Mikleš, J., Veselý, V., Chapter: Constrained Predictive Control of a Laboratory Servoengine. Slovak University of Technology Press, vol. 5, pp. 115-120, 2007.
- [6] Hirmajer, T., Fikar, M.: *Selected Topics in Modelling and Control*, Editor(s): Mikleš, J., Veselý, V., Chapter: Open-Loop Optimal Control of a Hybrid System. Slovak University of Technology Press, vol. 5, pp. 45-51, 2007.
- [7] Vasičkaninová, M., Bakošová, M.: *Selected Topics in Modelling and Control*, Editor(s): Mikleš, J., Veselý, V., Chapter: Fuzzy Logic Control of a Chemical Reactor With Disturbances. Slovak University of Technology Press, vol. 5, pp. 121-126, 2007.

IX.3 Article in journal

- [1] Čirka, L., Fikar, M.: A Toolbox for Recursive Identification of Dynamical Systems. *AT&P Journal PLUS 2*, pp. 44-47, 2007.
- [2] Herceg, M., Kvasnica, M., Čirka, L., Fikar, M.: Real-Time Predictive Control of a Servo Engine. *AT&P Journal PLUS 2*, pp. 124-130, 2007.
- [3] Herceg, M., Kvasnica, M., Fikar, M.: Stabilizing Predictive Control of Fuzzy Systems Described by Takagi-Sugeno Models. *AT&P Journal PLUS 2*, pp. 105-111, 2007.
- [4] Hirmajer, T., Čižniar, M., Fikar, M.: Application of a dynamic optimization method to solve optimal control problems. *AT&P Journal PLUS 2*, pp. 57-62, 2007.
- [5] Puna, D., Bakošová, M.: Algorithms for robust controller design: application to CSTR. *AT&P Journal PLUS 2*, pp. 79-83, 2007.
- [6] Závacká, J., Bakošová, M., Vaneková, K.: Control of systems with parametric uncertainties using a robust PI controller. *AT&P Journal PLUS 2*, pp. 84-87, 2007.

IX.4 Article in conference proceedings

- [1] Augustín, I.: LMS, an Application for E-learning in Physics. In *collection of annotations. Student competition STOČ'2007*, VŠB - Technical University Ostrava, 2007.
- [2] Bakošová, M.: LMS Moodle in the Course Control of Technological Processes. Editor(s): Huba, M., In *Proc. of 8th International Conference Virtual university 2007*, Bratislava, pp. 171-175, 2007.
- [3] Bakošová, M., Fikar, M., Čirka, L.: E-learning in Course on Process Control. Editor(s): Sedláček, J., In *Sborník příspěvků konference a soutěže eLearning 2007*, Gaudeamus, pp. 191-197, 2007.

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- [5] Bakošová, M., Puna, D.: Algorithms for Robust Controller Design: Application to CSTR. Editor(s): J. Mikleš, M. Fikar, M. Kvasnica, In *Proc. 16. Int. Conference Process Control '07, Štrbské Pleso, High Tatras, Slovakia*, (lecture: Puna), pp. 026f.pdf, 2007.
- [6] Bakošová, M., Puna, D., Závacká, J.: Robust stabilization of an exothermic CSTR. In *Proceedings of European Congress of Chemical Engineering (ECCE-6)*, Copenhagen, pp. CDROM 990.pdf, 2007.
- [7] Christophersen, F.J., Kvasnica, M., Jones, C.N., Morari, M.: Efficient Evaluation of Piecewise Control Laws defined over a Large Number of Polyhedra. Editor(s): S. G. Tzafestas, P. J. Antsaklis, In *Proc. of the European Control Conference 2007*, pp. 2360-2367, 2007.
- [8] Dovál, P., Čirka, L., Fikar, M.: EXPID - Experimental Identification Toolbox. In *15th Annual Conference Proceedings, KANAG - TISK, Praha, Kongresové centrum ČVUT Praha*, pp. 38-38, 2007.
- [9] Čirka, L., Bakošová, M., Fikar, M., Herceg, M.: Dynamic Simulations of Chemical Processes via the MATLAB Web Server. In *15th Annual Conference Proceedings, KANAG - TISK, Praha, Kongresové centrum ČVUT Praha*, pp. 34-34, 2007.
- [10] Čirka, L., Fikar, M.: LMS Moodle - Random Assignment. Editor(s): Huba, M., In *Proc. of 8th International Conference Virtual university 2007*, Bratislava, pp. 168-170, 2007.
- [11] Čirka, L., Fikar, M.: A Dynamical System Identification Toolbox. Editor(s): J. Mikleš, M. Fikar, M. Kvasnica, In *Proc. 16. Int. Conference Process Control '07, Štrbské Pleso, High Tatras, Slovakia*, pp. 001f.pdf, 2007.
- [12] Čirka, L., Fikar, M., Kvasnica, M.: Real-Time Adaptive Control of a Laboratory Fan Heater Using the Youla–Kučera Parameterisation. Editor(s): Fikar, M., Kolesárová, A., Bakošová, M., In *Proceedings IAM 2007 - workshop on informatics, automation and mathematics*, STU Press, pp. 99-110, 2007.
- [13] Čirka, L., Fikar, M., Kvasnica, M., Herceg, M.: New Features in Course on Experimental Identification. Editor(s): Huba, M., In *Proc. of 8th International Conference Virtual university 2007*, Bratislava, pp. 182-187, 2007.
- [14] Fikar, M., Čirka, L., Bakošová, M., Hirmajer, T.: Automatic Generation of Assignments and Quizzes in Control Engineering Education. Editor(s): S. G. Tzafestas, P. J. Antsaklis, In *Proc. of the European Control Conference 2007*, pp. 2714-2720, 2007.

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- [17] Fikar, M., Čirka, Ľ., Katuščák, S., Tiňo, R.: Information Technologies for the Project KNIHA.SK. Editor(s): J. Mikleš, M. Fikar, M. Kvasnica, In *Proc. 16. Int. Conference Process Control '07, Štrbské Pleso, High Tatras, Slovakia*, pp. 237f.pdf, 2007.
- [18] Herceg, M., Kvasnica, M., Čirka, Ľ., Fikar, M.: Real-time Predictive Control of a Servo Engine. Editor(s): J. Mikleš, M. Fikar, M. Kvasnica, In *Proceedings of the 16th Int. Conf. on Process Control*, pp. 222f.pdf, 2007.
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