DEPARTMENT OF SYSTEMS AND CONTROL

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The department is engaged in the analysis, control and optimization of systems and processes. The activities of the department are focused on the research of new methods and algorithms for automatic control, the development of procedures and tools to support the design of control systems, the development of specific measurement and control modules, and the development and construction of complete systems for the control and supervision of machines, devices and industrial processes.

Head:
Dr. Gregor Dolanc

The basic and applied research in 2018 was devoted to three sub-areas: methodologies for analysis and control systems design; tools and building blocks for implementation; and applied research in the priority problem domains.

The first topic addressed the *modelling and identification of nonlinear and complex dynamical systems*. The research on methods for the dynamical systems' modelling was pursued in the direction of the atmospheric variables modelling with Gaussian-process models. The main focus was on the Gaussian-process modelling method and the processing of very large amounts of measurement data.

The second topic was *advanced control.* We have continued the research and development of model predictive control (MPC) methods based on fast online optimization, with an emphasis on the fast-gradient method. For the dual fast-gradient method, which we are using for the plasma current and shape controller for the ITER tokamak fusion reactor, we have found an improved method of soft-constraints implementation with a reduced computational load, and analytically determined local convergence rates of the algorithm. With the implementation of the optimisation method using FPGA we have reached a computation time of 1 ms, which is sufficiently short for a practical implementation. Based on the primal fast-gradient method we have designed an improved MCP controller for the stabilization of the unstable resistive wall modes for ITER (Figure 1).

Within the framework of *prognostics and health management*, substantial progress was achieved in the field of fuel-cell diagnostics in 2018. Together with partner institutions within the INSIGHT project, we implemented an embedded system for data acquisition on an experimental system in CEA, France. On the bases of collected data, we developed several algorithms for feature extraction from fuel-cell impedance spectra. From the collected data, i.e., the parameters of equivalent circuit models, we will continue to develop an expert diagnostic system.

In the area of **tools and building blocks for implementation** we continued the design of the tool for the analysis and optimization of production performance. In 2018, we continued with work on the problem of material-resource planning. The research was focused on the planning problem where the due date and grouping constraints have to be considered. We have proposed more problem formulations described as an integer-programming problem, which can be applied for various situations that can appear in industry. The method was verified on the data sets from an industrial environment.

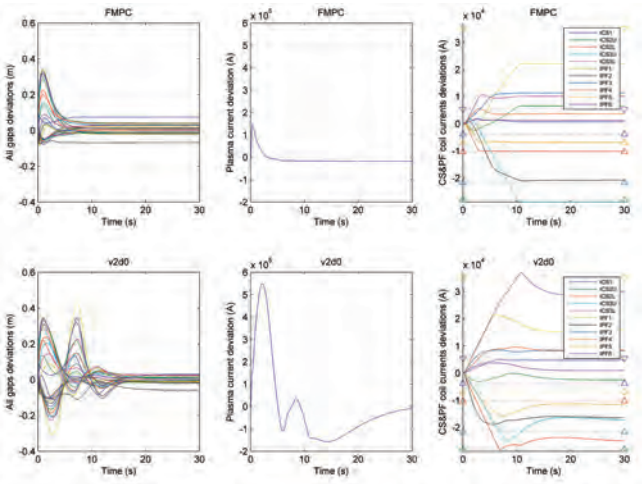

Figure 1: Simulation performance comparison between the MPC plasma current and shape control (top) and the reference CREATE v2d0 scheme (bottom): minor disturbance at t = 520 s. Left: plasma edge geometrical descriptors, centre: plasma current, right: poloidal field coil currents (dotted lines: constraints, with triangles marking their directions)

In the course of the three-year programme *Gostop - Building Blocks, tools and systems for factories of the future* we performed activities on both programme management as well as within the framework of R&D projects, where we participated in a number of R&D areas. In the area of the development of the prototype products for smart factories of the future, we participated in the development of two prototypes. First, a prototype module to provide 100% quality in a series of finished products on an example of an EC motors production line, and second, a prototype unit for remote process supervision and for the transfer of data from industrial devices through 4th-generation mobile networks. In the area of the development of a platform for the synthesis of models based on the production data, aimed at production process supervision, adaptive control and decision support, we developed the data analytics supporting modules, which were implemented in various analytical environments, in the form of web-services. In this R&D area, we also participated in building an architecture for the processing of complex data. In the area

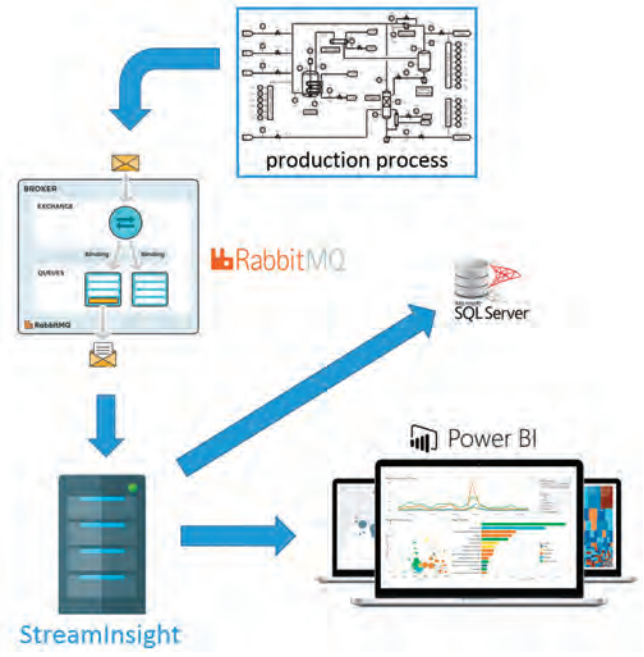

Figure 2: The architecture of the environment for complex data processing

of the development of an intelligent tool-management system, we defined a concept for some key components of the system (Figure 2). In the area of the development of the platform for an adaptive correction of the final product quality in the production of EC motors, we assessed the effect of the balancing parameters on the vibrations in the final product. In the area of the development of an experimental concept for an intelligent drive, we took part in the definition of the concept for the drive assemblies, in the definition of the algorithms for the control of torque and compliance and for the predictive maintenance of the drive assembly. We also took part in ensuring the connectivity of the drive assembly, according to the IoT concept, through the development of a specific Linux operating system, using the Yocto environment.

Applied research in the priority problem domains was the third sub-area of our interest. For the Slovenian Research Agency project *Method for the forecasting of local radiological pollution of atmosphere using Gaussian processes* models most of the activities were comprised of the evaluation of different Gaussian-process-based modelling methods for the identification of models useful for forecasting atmospheric variables. Dynamic models for wind and temperature profiles were identified.

Within the *State-of-health estimation of electrochemical energy systems* project, funded by the Slovenian Research Agency, two research tracks were executed in the last year of this project. The first one was focused on the development of time-domain fractional order identification methods with the purpose of implementing prognostics and health-management tasks. The second track was addressing the stochastic nature of the impedance data. The goal is to employ stochastic decision making for threshold selection and fault isolation. The experimental work is performed on the developed test beds as well as exploiting data from various ongoing H2020 projects in the area of fuel cells.

Following the initiative of the Republic of Slovenia for the establishment and operation of Strategic Innovative Partnerships within the framework of the Slovenian Smart Specialisation Strategy S4, the Strategic Innovative Partnership *Factories of the Future - SRIP ToP* is also operating. Our department has a very active role in SRIP ToP in the management of the area Control Technologies and in the implementation of the Multi-Annual Action Plan of this area. In 2018, a total of 38 Slovenian companies and academic institutions were gathered in this partnership, an implementation action plan was prepared, and a conference was organised where stakeholders were informed about the action plan and the possibilities for participation in its implementation.

International R&D projects

The scope of an international project H2020 *Memphys - MEMbrane based Purification of HYdrogen System* is the development of an electro-chemical system for hydrogen compression and cleaning using membranes, similar to the ones used in PEM fuel cells. The task of the Department of Systems and Control is the design of the hardware and the software for the control and diagnostic system. In the last year we finalized the experimental setup (Figure 3), developed and tested the control, diagnostic and condition monitoring algorithms and started with the development of a special electronic unit for fast data acquisition, control and diagnostics.

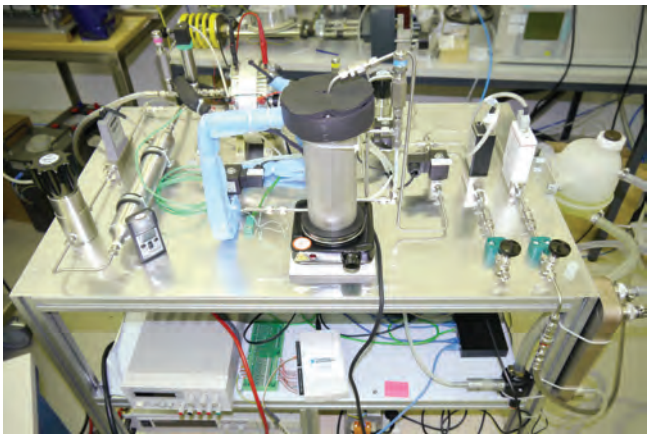

Figure 3: The experimental setup for the Memphys project.

In cooperation with leading academic and industrial partners in the field of solid-oxide fuel cells (SOFCs), we implement the three-year H2020 project *INSIGHT*. The project is aimed to develop the efficient tools for the on-line health monitoring of SOFC stacks, detection and isolation of the evolving degradation mechanisms and design of the accommodation actions. The IJS team contributes an innovative approach to the characterisation of SOFCs based on the dynamic response to the persistently excited stack and the identified mathematical model in terms of the lumped fractional order differential equations.

This year, in cooperation with TU Graz, Austria, we acquired a new bilateral research project that began in December 2018 to continue the ongoing successful cooperation in the field of fuel-cell fuel-status estimation. During 2018 we carried out some sustainable tests where we deliberately

initiated the degradation processes in fuel cells. On the basis of the obtained results, we improved the system for data acquisition and algorithms for their processing.

In 2018 we also collaborate in a new international project IAPUNIT, which is being implemented within the framework of the *European Defence Agency* (EDA). The project aims to develop an auxiliary fuel source for the fuel cells for military vehicles using F-34 military diesel fuel. This fuel is particularly problematic for usage in fuel cells due to impurities and, accordingly, an adjustment of the fuel processor's design is needed. The motivation for the project is to increase the energy efficiency, reduce noise levels, reduce thermal footprint and reduce pollution – all this in comparison to existing conventional diesel generators.

Applied work

In the course of a long-term collaboration with Danfoss Trata d.o.o., in 2018 we completed the development of hardware and software for the family of pressure-valve drives. The developed drives are able to automatically detect and reduce oscillations in the system by reducing the operating pressure. For Danfoss we also developed a prototype of a non-linear, high-speed drive and conducted a study of the indirect measurement of fluid flows based on some other physical quantities.

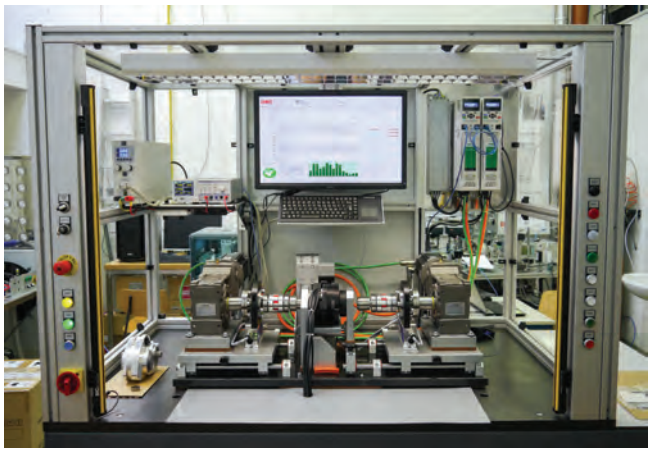

Figure 4: Diagnostic system for End-of-line control of electric drives for bicycles of the Pedelec type (Pedal Electric Cycle)

For the Domel Company, Železniki, Slovenia, we designed and built a semi-automatic diagnostic system for the end-of-line control of electric drives for bicycles of the Pedelec type (Figure 4). The mechanical part of the machine consists of two electrically driven helical bevel gear units for simulation of the driving torque and load, and of a manipulator to hold the unit under test during the operation. The diagnostic procedure consists of electrical tests of the control and communication loops, calibration of the internal sensors, encrypted programming of parameters, short run-in, test of torque assistance at several levels and speeds, free-run test, braking operation and safety functions. Also, vibrational tests are made in the range up to 5 kHz to detect unbalance of the motor, bearing or transmission problems. All measurements, measurement conditions and diagnostic results are saved into the data servers of the company.

In the field of wastewater treatment, we have started a study for the Kranj wastewater treatment plant, where the aim is to improve the settling of the sludge. Improper sludge settling is associated with the growth of filamentous bacteria and can lead to poor effluent quality. In the study, we analyse the plant's operating conditions, which potentially lead to the growth of filamentous bacteria, for example, high biomass concentration and sludge age, a low oxygen concentration in aerobic reactors, influent composition, etc. The analysis is performed by the developed mathematical model of the plant, data mining and by performing the changes to operational parameters directly on the process.

Educational and training activities

Some members of the department are giving lectures and practical courses at different faculties and universities: the Faculty of Electrical Engineering, University of Ljubljana, the Faculty of Logistics, University of Maribor, the University of Nova Gorica and the "Jožef Stefan" International Postgraduate School.

Some outstanding publications in the past year

1. Boškoski, Pavle, Debenjak, Andrej, Mileva Boshkoska, Biljana. Rayleigh copula for describing impedance data - with application to condition monitoring of proton exchange membrane fuel cells. *European journal of operational research*, ISSN 0377-2217. [Print ed.], 2018, vol. 266, no. 1, pp. 269-277 [COBISS.SI-ID 30736167]
2. Gerkšič, Samo, Pregelj, Boštjan, Perne, Matija, Ariola, M., De Tommasi, Gianmaria, Pironti, Alfredo. Model predictive control of ITER plasma current and shape using singular-value decomposition. *Fusion engineering and design*, ISSN 0920-3796. [Print ed.], 2018, vol. 129, pp. 158-163, [COBISS.SI-ID 31239463]
3. Glavan, Miha, Gradišar, Dejan, Humar, Iztok, Vrančić, Damir. Refrigeration control algorithm for managing supermarket's overall peak power demand. *IEEE transactions on control systems technology*, ISSN 1063-6536. [Print ed.], 2018, [COBISS.SI-ID 31573799]
4. Vrečko, Darko, Nerat, Marko, Vrančić, Damir, Dolanc, Gregor, Dolenc, Boštjan, Pregelj, Boštjan, Meyer, Fabien, Au, Siu Fai, Makkus, Robert, Juričić, Đani. Feedforward-feedback control of a solid oxide fuel cell

power system. *International journal of hydrogen energy*, ISSN 0360-3199. [Print ed.], 2018, vol. 43, no. 12, pp. 6352-6363, [COBISS.SI-ID 31267367]
5. Nerat, Marko, Juričić, Đani. Modelling of anode delamination in solid oxide electrolysis cell and analysis of its effects on electrochemical performance. *International journal of hydrogen energy*, ISSN 0360-3199. [Print ed.], 2018, vol. 43, no. 17, pp. 8179-8189, [COBISS.SI-ID 31331367]

Some outstanding achievements in the past year

1. Our department is a partner in the project *IAPUNIT - Development of an innovative auxiliary power unit for military purposes based on high-temperature PEM fuel cell and reforming technology based on military logistic consumable materials* for the European Defence Agency EDA
2. European Patent Office approved the patent *Reducing oscillations in a control system: patent EP 2356522 B1* to members of our department, dr. Janko Petrovčič and doc. dr. Damir Vrančić.
3. For the company Domel doo, Železniki we developed and put into operation a diagnostic system for electric bicycle drives
4. The *Technology Network Advanced Control Technologies* award for the best master thesis in 2018 was granted to Matic Knap for his work entitled *Simulation of magnetic plasma shape control in ITER tokamak* that was carried out on our department under the mentorship of dr. Samo Gerkšič.

INTERNATIONAL PROJECTS

1. H2020 - MEMPHYS; Membrane based Purification of Hydrogen System
   Dr. Gregor Dolanc
   European Commission
2. H2020 - INSIGHT; Implementation in Real SOFC Systems of Monitoring and Diagnostic Tools Using Signal Analysis to Increase their Lifetime
   Prof. Đani Juričić
   European Commission
3. Health Monitoring and Lifetime Prediction of Solid Oxide Fuel and Electrolysis Cells
   Prof. Đani Juričić
   Slovenian Research Agency
4. Non-invasive Condition Monitoring of High Temperature Steam Electrolyser
   Prof. Đani Juričić
   Slovenian Research Agency

RESEARCH PROGRAM

1. Program systems and control
   Prof. Đani Juričić

R & D GRANTS AND CONTRACTS

1. On-line Degradation Monitoring for Extended Durability of High Temperature Steam Electrolysers
   Prof. Đani Juričić
2. Degradation monitoring and performance optimisation of solid oxide electrolysis cells
   Prof. Đani Juričić
3. State-of-health prognostics of electrochemical energy systems
   Dr. Pavle Boškoski
4. E-maintenance of electro-mechanical drives: prognostics and health management solutions under non-stationary operating conditions
   Prof. Đani Juričić
5. Method for the forecasting of local radiological pollution of atmosphere using Gaussian process models
   Prof. Juš Kocijan
6. Building blocks, tools and systems for the Factories of the Future – GOSTOP
   Dr. Vladimir Jovan
   Ministry of Education, Science and Sport
7. Development of the Control System for the Gas Fuel Processor / Fuel Cell System (Phase 1)
   Dr. Gregor Dolanc
   Frauenhofer-gesellschaft zur Foerderung der

NEW CONTRACTS

1. Development and implementation of the device for bicycle electric drives testing
   Dr. Janko Petrovčič
   Domel , d. o. o.
2. Quality inspection device for Pedelec eBike
   Dr. Janko Petrovčič
   Domel , d. o. o.
3. Development of new drive „ Flat Station“
   Asst. Prof. Damir Vrančić
   Danfoss Trata, d. o. o.

VISITORS FROM ABROAD

1. Armando Salvati, University of Salerno, Fisciano (SA), Italy, 16 March 2018
2. Pietro De Stefano, University of Salerno, Fisciano (SA), Italy, 20 April to 17 July 2018
3. Shambu Nath Sharma, National Institute of Technology, Surat, India, 20 May to 20 June 2018
4. Matija Dubravac, Bjelovar University of Applied Sciences, Bjelovar, Croatia, 2 July to 31 August 2018
5. Vanja Subotić, Technische Universität Graz, Graz, Austria, 13–14 September 2018
6. Cagla Kuru, Dogus University, Istanbul, Turkey, 1 October 2018 to 31 March 2019
7. Muzaffer Oyan, Dogus University, Istanbul, Turkey, 1 October 2018 to 31 March 2019
8. Jovan Stefanovski. Ss. Cyril and Methodius University in Skopje, Skopje, Macedonia, 24–27 October 2018
9. Allard van Baalen, HyET, Arnhem, Netherlands, 18 November to 23 December 2018

STAFF

Researchers

1. Dr. Pavle Boškoski
2. **Dr. Gregor Dolanc, Head**
3. Dr. Samo Gerkšič
4. Dr. Giovanni Godena
5. Dr. Dejan Gradišar
6. Dr. Nadja Hvala
7. Dr. Vladimir Jovan
8. Prof. Đani Juričić
9. Prof. Juš Kocijan
10. *Dr. Bojan Musizza, left 01.11.18*
11. Dr. Marko Nerat
12. Dr. Matija Perne
13. Dr. Janko Petrovčič
14. Dr. Boštjan Pregelj
15. Asst. Prof. Damir Vrančić
16. Dr. Darko Vrečko

Postdoctoral associates

17. *Dr. Andrej Debenjak, left 01.05.18*
18. Dr. Boštjan Dolenc

19. Dr. Miha Glavan

Postgraduates

20. Tomaž Kos, B. Sc.
21. Tadej Krivec, B. Sc.
22. Gjorgji Nusev, B. Sc.
23. Martin Stepančič, B. Sc.
24. Luka Žnidarič, B. Sc.

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25. Stanislav Černe, B. Sc.
26. Primož Fajdiga, B. Sc.

Technical and administrative staff

27. Maja Janežič, B. Sc.
28. Miroslav Štrubelj

BIBLIOGRAPHY

Original Article

1. Pavle Boškoski, Andrej Debenjak, Biljana Mileva Boshkoska, "Rayleigh copula for describing impedance data - with application to condition monitoring of proton exchange membrane fuel cells", *European journal of operational research*, 2018, **266**, 1, 269-277.
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4. Darko Vrečko, Marko Nerat, Damir Vrančić, Gregor Dolanc, Boštjan Dolenc, Boštjan Pregelj, Fabien Meyer, Siu Fai Au, Robert Makkus, Đani Juričić, "Feedforward-feedback control of a solid oxide fuel cell power system", *International journal of hydrogen energy*, 2018, **43**, 12, 6352-6363.
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6. Julian Walker, Thorsten J. M. Bayer, Maja Makarovič, Tomaž Kos, Susan Trolier-McKinstry, Barbara Malič, Tadej Rojac, "Cobalt doping to influence the electrical conductivity of $(Bi_{0.91}Dy_{0.09})FeO_3$ ceramics", *Materials letters*, 2018, **225**, 126-129.
7. Juš Kocijan, "Parameter estimation of a nonlinear benchmark system", *Science, Engineering & Education*, 2018, **3**, 1, 3-10.
8. Dejan Gradišar, Hua Shao, Boštjan Grašič, "Evaluation of delta tool for comparison of different air quality prediction models", *Science, Engineering & Education*, 2018, **3**, 1, 11-16.
9. Juš Kocijan, Dejan Gradišar, Martin Stepančič, Marija Božnar, Boštjan Grašič, Primož Mlakar, "Selection of the data time interval for the prediction of maximum ozone concentrations", *Stochastic environmental research and risk assessment*, 2018, **32**, 6, 1759-1770.
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11. Nadja Hvala, Darko Vrečko, Cirila Bordon, "Plant-wide modelling for assessment and optimization of upgraded full-scale wastewater treatment plant performance", *Water practice and technology*, 2018, **13**, 3, 566-582,

Published Conference Contribution

1. Gjorgji Nusev, Boštjan Dolenc, Vanja Subotić, Christoph Hochenauer, Đani Juričić, Pavle Boškoski, "EIS through time-domain fractional order identification", In: *Abstract book*, 11th International Workshop on Impedance Spectroscopy, IWIS 2018, 26-28 September 2018, Chemnitz, DE, 36.
2. Paulo Moura Oliveira, Damir Vrančić, "Swarm design of series PID cascade controllers", In: Alberto Cardoso (ed.), *Controlo 2018: proceedings*, 2018, 276-281.
3. Damir Vrančić, Paulo Moura Oliveira, Mikuláš Huba, "Optimizing disturbance rejection by using model-based compensator with user-defined high-frequency gains", In: Alberto Cardoso (ed.), *Controlo 2018: proceedings*, 2018, 330-335.
4. Gjorgji Nusev, Pavle Boškoski, Marko Bohanec, Biljana Mileva Boshkoska, "A DSS model for selection of computer on module based on PROMETHEE and DEX methods", In: Fátima Dargam (ed.), *Decision Support Systems VIII: sustainable data driven and evidence-based decision support: 4th International Conference, ICDSST 2018 Heraklion, Greece, May 22-25, 2018: proceedings*, (Lecture notes in business information processing **313**), 2018, 157-168.
5. Boštjan Dolenc, Damir Vrančić, Darko Vrečko, Đani Juričić, "Maximizing the electrical efficiency of a solid oxide fuel cell system", In: *European Control Conference, ECC 2018, 2-15 June 2018, Limassol, Cyprus: final program*, 2018, 1881-1887.
6. José Marín-Medina, Juan Carlos Seck-Tuoh-Mora, Norberto Hernandez-Romero, A. Karelin, Federico Nuñez-Piña, Dejan Gradišar, "The flow shop scheduling problem modeled by means of times place Petri nets'", In: Sio-Iong Ao (ed.), *IAENG transactions on engineering sciences: special issue for the International Association of Engineers Conferences 2016. Volume II*, 2018, 275-288.
7. Mikuláš Huba, Damir Vrančić, "Comparing filtered PI, PID and $PIDD^2$ control for the FOTD plants", In: *PID'18*, 3rd IFAC Conference on Advances in Proportional-Integral-Derivative Control, Ghent, Belgium, May 9-11, 2018, 2018, 954-959.
8. Damir Vrančić, Mikuláš Huba, Paulo Moura Oliveira, "PID controller tuning for integrating processes", In: *PID'18*, 3rd IFAC Conference on Advances in Proportional-Integral-Derivative Control, Ghent, Belgium, May 9-11, 2018, 2018, 586-591.
9. Boštjan Dolenc, Gjorgji Nusev, Vanja Subotić, Christoph Hochenauer, Nicole Gegring, Đani Juričić, Pavle Boškoski, "Fractional-order model identification for state of health assessment of solid-oxide fuel cells", In: *Proceedings of the 10th IFAC Symposium on Fault Detection, Supervision and Safety for Technical Processes SAFEPROCESS 2018, Warsaw, Poland, 29-31 August 2018*, (IFAC papersOnline **51**), 2018, 24, 849-854.
10. Boštjan Dolenc, Gjorgji Nusev, Vanja Subotić, Nicole Gehring, Đani Juričić, Pavle Boškoski, "SOFC characterisation based on an algebraic fractional-order identification approach", In: Ellen Ivers-Tiffée (ed.), *Proceedings of the 13th European SOFC & SOE Forum 2018, Lucerne, Switzerland: advanced characterisation techniques I+II*, 2018, 89-97.
11. Mikuláš Huba, Damir Vrančić, "Introduction to the discrete time PID_n^m control for the IPDT Plant", In: *Proceedings of the 15th IFAC Conference on Programmable Devices and Embedded Systems, PDeS 2018, Ostrava, Czech Republic, 23-25 May 2018*, (IFAC papersOnline **51**), 2018, **51**, 6, 119-124.
12. Mitja Jančič, Juš Kocijan, Boštjan Grašič, "Identification of atmospheric variable using deep Gaussian processes", In: *Proceedings of the 1st IFAC Workshop on Integrated Assessment Modelling for Environmental System, IAMES 2018, May 10-11, 2018, Brescia, Italy*, (IFAC papersOnline **51**), 2018, 5, 43-48.