DYCOPS-CAB 2016

11th IFAC Symposium on Dynamics and Control of Process Systems, including Biosystems

Trondheim, Norway
June 6-8, 2016

IFAC
INTERNATIONAL FEDERATION
OF AUTOMATIC CONTROL

Host organization:

NTNU
Norwegian University of Science and Technology

Main sponsors:

Gemini Center PROST – Advanced Process Control, at NTNU and SINTEF

NTNU SINTEF

Statoil

Norway IFAC NMO:

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National organizing committee:

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Lars Imsland	NTNU, NOC co-chair
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Welcome message from the NOC chairs

Welcome to the DYCOPS-CAB 2016 symposium and welcome to Trondheim!

Trondheim is a university city and with more than 30 thousand students its overall population is about 200 thousand. Trondheim was officially founded in 997 by the Viking King Olav Tryggvason, whose statue you can see on top of the pillar in the city center, but Trondheim is even more famous for another Olav.

This is Olav “the holy” Haraldson who in 1030 was killed in a battle north of Trondheim in his struggle to christen Norway. He was buried in Trondheim (then known as Nidaros) and was soon declared as a Saint by the church. The most famous attraction in Trondheim is the Nidaros Cathedral, which was raised in his honor. Construction started in 1070, but it has been under continuous rebuilding since. Although not a large cathedral in a European setting, it is the largest in Scandinavia, and was at its time an enormous achievement for Norway.

The Mayor of the city of Trondheim is happy to invite all participants to an organ concert in Nidarosdomen at 1830 on Monday.

The second most well-known building in Trondheim is probably the NTNU main building which looks down on the cathedral. The Norwegian University of Science and Technology (NTNU) is after some recent mergers the largest university in Norway with about 40 000 students, and it is the only university in Norway with a full engineering school.

On the NTNU campus, you will also find SINTEF, originally founded by NTNU Professors, which by now, with more than 2000 employees, is one of Europe’s largest independent research organizations. The process control groups at NTNU and SINTEF work together in a “Gemini center” called PROST, and PROST is the main sponsor for the DYCOPS-CAB symposium.

Trondheim is also well known for the river Nidelven. It comes from the Selbu lake nearby, so it is a short river, but per km river this is the best salmon river in Norway! The conference dinner on Tuesday will be at the Royal Garden Hotel, which has a nice location just next to the river.

We hope you all have a great time in Trondheim!

Sigurd Skogestad (NOC chair)

Lars Imsland (NOC co-chair)

International Program Committee

Chairs

Hector Budman (CAN)	IPC chair
Ilse Smets (BEL)	IPC co-chair
Krister Forsman (SWE)	IPC industrial co-chair

Area Co-Chairs

Juergen Hahn (USA)	Model based Control
Manabu Kano (JPN)	Modelling and System Identification
Vinay Kariwala (IND)	Process Optimization and Plantwide Control
Maria Klapa (GRE)	Metabolic Engineering and Systems Biology
Ahmet Palazoglu (USA)	Performance and Fault monitoring
Gabriele Pannocchia (ITA)	Batch Processes
Marie-Noëlle Pons (FRA)	Environmental and Energy Biosystems
Udo Reichl (GER)	Bioreactor Technology
Lakshminarayanan Samavedham (SGP)	Process Planning and Scheduling

IPC Members

Dycops stream

Frank Allgöwer (GER)
Mazen Alamir (FRA)
Jesus Alvarez (MEX)
Jie Bao (AUS)
Don Bartusiak (USA)
Dominique Bonvin (CHE)
Wayne Bequette (USA)
Richard Braatz (USA)
Eduardo Camponogara (BRA)
Denis Dochain (BEL)
Sebastian Engell (GER)
Rolf Findeisen (GER)
Bjarne Foss (NOR)
Furong Gao (CHN)
Martin Guay (CAN)
Ravi Gudi (IND)
Biao Huang (CAN)
Lars Imsland (NOR)
Alf Isaksson (SWE)
Nitin Kaistha (IND)
Jay H. Lee (KOR)
Jong-Min Lee (KOR)
Tao Liu (CHN)
Cesar de Prada (ESP)
Stratos Pistikopoulos (USA)
S. Joe Qin (USA)
Claudio Scali (ITA)
Sirish Shah (CAN)
Sigurd Skogestad (NOR)
Moses Tade (AUS)

Biosystems stream

Julio Banga (ESP)
Nadi Bar (NOR)
Olivier Bernard (FRA)
Anton van Boxtel (NLD)
Eric Bullinger (GER)
Benoit Chachuat (GBR)
Francesco Corona (FIN)
Jakob K. Huusom (DEN)
Brian Ingalls (CAN)
Elling W. Jacobsen (SWE)
Jaime Moreno (MEX)
Michela Mulas (FIN)
Michel Perrier (CAN)
Jesús Picó (ESP)
Isabelle Queinnec (FRA)
Isabel Rocha (POR)
Ivan Simeonov (BGR)
Hong Yue (UK)

Welcome message from the IPC chairs

On behalf of the International Programming Committee, we would like to welcome you to the DYCOPS-CAB 2016 symposium. This is the first time that DYCOPS and CAB are offered together as one single event.

The DYCOPS symposia have a long history initiated in 1986 under the name DYCORD (Dynamics and Control of Chemical Reactors, Distillation Columns and Batch Processes) in Bournemouth (UK) and renamed into DYCOPS in 1998 during the fifth edition in Corfu (Greece). DYCOPS 2016 will be the eleventh edition. CAB originated from a series of events that started 40 years ago in Dijon, France with the aim of stimulating contacts between specialists active in academic research and industrial development in all areas of biotechnology.

Following a rigorous reviewing process, the International Program Committee selected 205 papers for presentation. The program consists of 25 regular sessions, 7 invited sessions, 1 poster session, 8 keynote lectures (of which 4 are invited keynotes and 4 were selected from the contributions), and 3 plenary sessions. Following the tradition of previous conferences, each morning begins with a plenary talk. The regular and invited sessions are split into four parallel tracks, one in the morning and two sessions in the afternoon. Poster presentations take place on Monday afternoon. The program is complemented by two very interesting preconference workshops that take place on Sunday, June 5th.

We wish you a very enjoyable stay in Trondheim and a productive conference.

Hector Budman (IPC chair)

Ilse Smets (IPC co-chair)

Practical information

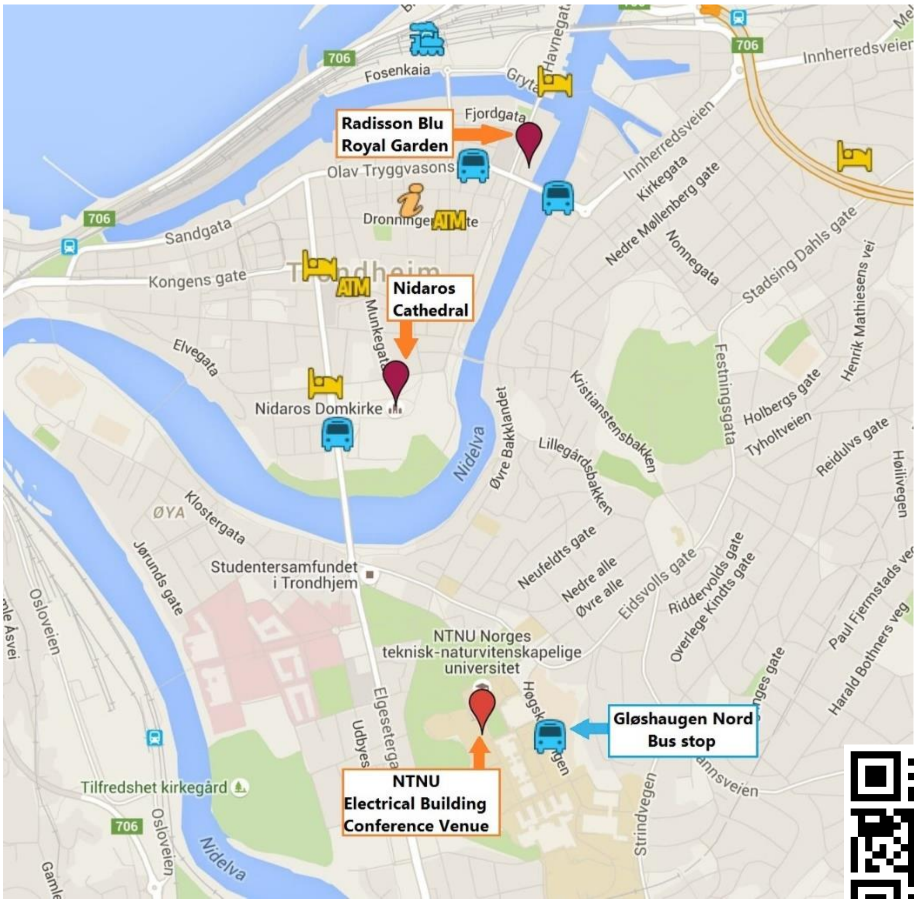
The workshops on Sunday take place at the conference venue (see Program at a Glance). Also the welcoming reception, at 1800, is held at the same place.

Monday at 1830 there will be the Mayor's concert in Nidarosdomen (Nidaros Cathedral, see map below, larger at last page), held especially for the conference. The concert is open for all conference participants (and their spouse/guest).

The conference dinner is Tuesday 1900 at Radisson Blu Royal Garden Hotel (see map). The dinner is included for both regular and student registrations.

For traveling between the city center (hotels, Nidarosdomen, conference dinner) and the conference venue, there are the following options:

- Walking to the conference venue from the city center is about 20 min. Nidarosdomen is 10-15 min. from the conference venue.
- City busses run frequently between the city center and the conference venue at NTNU Gløshaugen. All southbound buses takes you close to the venue, most convenient is perhaps route no. 5 (Dragvoll) and no. 22, and departing at "Gløshaugen nord" (see map last page). Bus fare is NOK 50 for a single trip if you pay by cash onboard. Cheaper options are the 72 hour card or the disposable card that can be bought in several retail stores (see https://www.atb.no/fares/category1497.html).
- Taxi fare from the city center to the conference venue at Gløshaugen is NOK 100-150.



Program at a Glance

DYCOPS-CAB 2016 Technical Program Sunday June 5, 2016

<table>
<tr><th>Track T1</th><th>Track T2</th></tr>
<tr><td colspan="2">08:00-08:30 SuWReg

Workshop Registration</td></tr>
<tr><td>08:30-12:30 SuAT1

Nonlinear State and Parameter Estimation without Tears AM</td><td>08:30-12:30 SuAT2

Open</td></tr>
<tr><td colspan="2">12:30-13:30 SuLunch_Break

Lunch</td></tr>
<tr><td>13:30-17:30 SuBT1

Nonlinear State and Parameter Estimation without Tears PM</td><td>13:30-17:30 SuBT2

Making Model-Based Optimizing Control an Industrial Reality – Results from the MOBOCON Project</td></tr>
<tr><td colspan="2">17:30-18:00 SuCReg

Registration</td></tr>
<tr><td colspan="2">18:00-19:00 SuRecepion

Welcoming Reception</td></tr>
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DYCOPS-CAB 2016 Technical Program Monday June 6, 2016

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<tr><th>Track 1</th><th>Track 2</th><th>Track 3</th><th>Track 4</th></tr>
<tr><td colspan="4">08:00-08:45 MoRG

Registration</td></tr>
<tr><td colspan="4">08:45-09:00 MoOC
Room T1
Opening Ceremony</td></tr>
<tr><td colspan="4">09:00-09:55 MoPL
Room T1
Plenary I Manfred Morari: "Process Control and Beyond"</td></tr>
</table>

<table>
<tr><td colspan="4">10:00-10:30 MoAM_Coffee_Break

Coffee Break</td></tr>
<tr><td>10:30-12:10 MoA1
Room T3
Performance and Fault Monitoring I</td><td>10:30-12:10 MoA2
Room T1
Advances in Predictive Control</td><td>10:30-12:10 MoA3
Room T4
Control and Optimization of Batch Processes</td><td>10:30-12:10 MoA4
Room T2
Bioreactor Process Observers and Optimization</td></tr>
<tr><td colspan="4">12:10-13:00 MoLunch_Break

Lunch Break</td></tr>
<tr><td>13:00-14:00 MoB1
Room T2
Process Optimization and Plantwide Control I</td><td>13:00-14:00 MoB2
Room T1
Model Based Control I</td><td>13:00-14:00 MoB3
Room T4
Control Applications in Chromatographic Separation Processes</td><td>13:00-14:00 MoB4
Room T3
Control Applications I</td></tr>
<tr><td>14:05-14:35 MoC1
Room T2
Short oral presentations of posters: Computer Applications in Biology and Biotechnology</td><td>14:05-14:35 MoC2
Room T1
Short oral presentations of posters: Model Based Control</td><td>14:05-14:35 MoC3
Room T3
Short oral presentations of posters: Modelling and System Identification</td><td>14:05-14:35 MoC4
Room T4
Short oral presentations of posters: Control Applications/Fault Detection</td></tr>
<tr><td colspan="4">14:35-15:50 MoPM_Coffee_Break

Display of Posters</td></tr>
<tr><td>15:50-17:30 MoD1
Room T1
Process Optimization and Plantwide Control II</td><td>15:50-17:30 MoD2
Room T3
Micro and Nanotechnology Applications</td><td>15:50-17:30 MoD3
Room T2
Modeling of Biological Systems</td><td>15:50-17:30 MoD4
Room T4
Inferential Sensing, State Estimation and Sensor Development I</td></tr>
</table>

<table>
<tr><td>18:30-20:30 MoConcert

Concert in Nidarosdomen</td></tr>
</table>

DYCOPS-CAB 2016 Technical Program Tuesday June 7, 2016

Track 1	Track 2	Track 3	Track 4
08:00-08:15 TuRG Registration			
08:15-09:10 TuPL Room T1 Plenary II Krister Forsman: "Implementation of Advanced Control in the Process Industry without the Use of MPC"			

09:15-09:45 TuK1N1 Room T1 Keynote III Heiko Peterson: "Control Loop Performance Monitoring – ABB's Experience Over Two Decades"	09:15-09:45 TuK1N2 Room T2 Keynote I Gabriele Pannocchia: "Parsimonious Cooperative Distributed MPC for Tracking Piece-Wise Constant Setpoints"
09:45-10:15 TuK2N1 Room T1 Keynote II Manabu Kano: "Vinyl Acetate Monomer (VAM) Plant Model : A New Benchmark Problem for Control and Operation Study"	09:45-10:15 TuK2N2 Room T2 Keynote IV Miguel Mauricio-Iglesias: "Operation of an Innovative WWTP with Environmental Objectives. A Model-Based Analysis"

10:15-10:30 TuAM_Coffee_Break Coffee Break			
10:30-12:10 TuA1 Room T1 Industrial Control Applications	10:30-12:10 TuA2 Room T3 Model Based Control II	10:30-12:10 TuA3 Room T2 Bioreactor Process Monitoring and Modeling	10:30-12:10 TuA4 Room T4 Application of PSE Tools to CO2 Capture, Utilization and Storage
12:10-13:00 TuLunch_Break Lunch Break			
13:00-15:00 TuB1 Room T1 Process Planning and Scheduling	13:00-15:00 TuB2 Room T4 Performance and Fault Monitoring II	13:00-15:00 TuB3 Room T3 Plantwide Control and Distillation	13:00-15:00 TuB4 Room T2 Modeling and Control Techniques for Artificial Pancreas Systems
15:00-15:30 TuPM_Coffee_Break Coffee Break			
15:30-17:30 TuC1 Room T2 Optimization in Systems Biotechnology and Systems Medicine	15:30-17:30 TuC2 Room T1 Energy and Power Systems	15:30-17:30 TuC3 Room T4 Modelling and System Identification I	15:30-17:30 TuC4 Room T3 Control Applications II

19:00-22:00 TuDinner Conference Dinner, Radisson Blu Royal Garden Hotel

DYCOPS-CAB 2016 Technical Program Wednesday June 8, 2016

<table>
<tr><th>Track 1</th><th>Track 2</th><th>Track 3</th><th>Track 4</th></tr>
<tr><td colspan="4">08:00-08:15 WeRG

Registration</td></tr>
<tr><td colspan="4">08:15-09:10 WePL
Room T1
Plenary III Vassily Hatzimanikatis: "Analysis and Design of Metabolic Networks under Uncertainty"</td></tr>
</table>

<table>
<tr><td colspan="2">09:15-09:45 WeK1N1
Room T1
Keynote VI B. Erik Ydstie: “Stability of Multi-Phase Systems Evolving on an Equilibrium Manifold”</td><td colspan="2">09:15-09:45 WeK1N2
Room T2
Keynote V Radhakrishnan Mahadevan: “A Multi-Scale Model of the Whole Human Body Based on Dynamic Parsimonious Flux Balance Analysis”</td></tr>
<tr><td colspan="2">09:45-10:15 WeK2N1
Room T1
Keynote VII Andrea Cortinovis: “Dynamic Time to Surge Computation for Electric Driven Gas Compressors During Voltage Dips”</td><td colspan="2">09:45-10:15 WeK2N2
Room T2
Keynote VIII Alexander Schaum: “Pointwise Innovation-based State Observation of Exothermic Tubular Reactors”</td></tr>
<tr><td colspan="4">10:15-10:30 WeAM_Coffee_Break

Coffee Break</td></tr>
<tr><td>10:30-12:10 WeA1
Room T1
Model Based Control III</td><td>10:30-12:10 WeA2
Room T4
Modelling and System Identification II</td><td>10:30-12:10 WeA3
Room T3
Performance and Fault Monitoring III</td><td>10:30-12:10 WeA4
Room T2
Modeling and Control of Microalgae Processes</td></tr>
<tr><td colspan="4">12:10-13:00 WeLunch_Break

Lunch Break</td></tr>
<tr><td>13:00-15:00 WeB1
Room T1
Model Based Control IV</td><td>13:00-15:00 WeB2
Room T2
Modelling and System Identification III</td><td>13:00-15:00 WeB3
Room T3
Modeling, Optimization and Control in Biological Waste/water Treatment</td><td>13:00-15:00 WeB4
Room T4
Inferential Sensing, State Estimation and Sensor Development II</td></tr>
<tr><td colspan="4">15:00-15:30 WePM_Coffee_1
Room T1
Closing Ceremony</td></tr>
</table>

Workshops Sunday 05 June

Workshop 1: Nonlinear State and Parameter Estimation without Tears (AM+PM)

Organizers:

- R. Bhushan Gopaluni, Associate Professor, Department of Chemical and Biological Engineering (University of British Columbia, Canada)
- Sachin C. Patwardhan, Professor, Department of Chemical Engineering (Indian Institute of Technology Mumbai, India)
- Lorenz T. Biegler, Professor, Department of Chemical Engineering (Carnegie Mellon University, USA)
- Aditya Tulsyan, Postdoctoral Associate, Department of Chemical Engineering (Massachusetts Institute of Technology, USA)

Workshop 2: Making model-based optimizing control an industrial reality – Results from the MOBOCON project (PM)

Organizers:

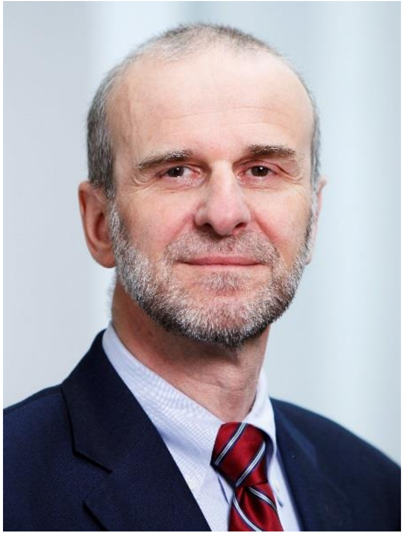
- Radoslav Paulen, Sebastian Engell (Process Dynamics and Operations Group, Technische Universität Dortmund, Dortmund, Germany)
- Andreas Potschka, Hans Georg Bock (Interdisciplinary Center for Scientific Computing, Heidelberg, Germany)

Plenary Monday

Manfred Morari

Process Control and Beyond

Abstract: Reflecting on our work over the last 40 years I found that it was dominated by two themes: Computation and Uncertainty. I will describe how the rapidly increasing computational resources have affected our approaches to deal with uncertainty in feedback control. The talk will be illustrated by examples from process control and other application areas like automotive and power systems.



Bio: Manfred Morari was head of the Department of Information Technology and Electrical Engineering at ETH Zurich from 2009 to 2012 and head of the Automatic Control Laboratory from 1994 to 2008. Before that he was the McCollum-Corcoran Professor of Chemical Engineering and Executive Officer for Control and Dynamical Systems at the California Institute of Technology. From 1977 to 1983 he was on the faculty of the University of Wisconsin. He obtained the diploma from ETH Zurich and the Ph.D. from the University of Minnesota, both in chemical engineering.

His interests are in hybrid systems and the control of biomedical systems. Morari's research is internationally recognized. The analysis techniques and software developed in his group are used in universities and industry throughout the world. He has received numerous awards, including the Eckman Award, Ragazzini Award and Bellman Control Heritage Award from the American Automatic Control Council; the Colburn Award, Professional Progress Award and CAST Division Award from the American Institute of Chemical Engineers; the Control Systems Technical Field Award and the Bode Lecture Prize from IEEE. He is a Fellow of IEEE, AIChE and IFAC. In 1993 he was elected to the U.S. National Academy of Engineering, in 2015 to the UK Royal Academy of Engineering. Manfred Morari served on the technical advisory boards of several major corporations.

Plenary Tuesday

Krister Forsman

Implementation of Advanced Control in the Process Industry without the Use of MPC

Abstract: In the process industry, such as chemical, pulp and paper or petrochemical industry there are plenty of processes that require multivariable control. Classical control structures that handle this, for example cascade control, feedforward, ratio control, and parallel control have been used at least since the 1930s. Today, much focus in academia is on model predictive control (MPC). In this paper we discuss the comparative advantages and disadvantages of classical control structures and MPC.

Bio: Krister Forsman has more than 20 years of practical experience from automatic control, industrial IT and Manufacturing Execution Systems in process industry, primarily the chemical and pulp and paper industries. He received his PhD in mathematical control theory in 1991, from Linköping University, Sweden. After ten years in various positions within the ABB group, he ran his own consulting company for a few years. In 2005 he joined the Perstorp group as a Corporate Specialist. Krister has worked with around 60 different plants in some 20 countries. He has authored some 50 articles and conference papers in process control and related areas, and a textbook in practical process control. Since 2012 he is also an adjunct professor at the Department of Chemical Engineering at the Norwegian University of Science and Technology (NTNU). His main research interests are control structures for industrial applications and plantwide control.

Plenary Wednesday

Vassily Hatzimanikatis

Analysis and Design of Metabolic Networks under Uncertainty

Abstract: Metabolic engineering and synthetic biology involve the design and retrofitting of genome-scale metabolic networks through the manipulation of enzyme activities. Efficient design requires the use of mathematical models that account for the reaction mechanisms of the enzymes, and their thermodynamic and kinetic properties. We present the recent developments of a workflow for the development of genome-scale kinetic models of metabolic networks. The workflow is called ORACLE (Optimization and Risk Analysis of Complex Living Entities) and it accounts for the uncertainty and incompleteness of the available experimental information used in model development and parametrization.

ORACLE addresses the following fundamental problem:

Given:

(a) a set of observed conditions of cellular physiology,
(b) a genome-scale stoichiometric model of metabolism,
(c) a (partial) flux profile in this network associated with the physiological conditions, and
(d) a (partial) profile of metabolite concentrations

find

a family of nonlinear kinetic models and the associated distribution of the kinetic parameters that are consisistent with the information above.

The availability of kinetic models of metabolic networks allows the development and application of methods from optimization, dynamics and control of process systems approaches for analysis and design. We will demonstrate the application of ORACLE for the design and optimization of the production of industrial chemicals by *E. coli* and *S. cerevisiae*.

Bio: Dr. Vassily Hatzimanikatis is currently Associate Professor of Chemical Engineering and Bioengineering at Ecole Polytechnique Federale de Lausanne (EPFL), in Lausanne, Switzerland. Vassily received a PhD and an MS in Chemical Engineering from the California Institute of Technology, and his Diploma in Chemical Engineering from the University of Patras, in Greece. After the completion of his doctoral studies, he held a research group leader position at the Swiss Federal Institute of Technology in Zurich (ETHZ), Switzerland. Prior to joining EPFL, Vassily has been assistant professor at Northwestern University, at Illinois, USA, and he worked for three years in DuPont and Cargill.

Vassily is associate editor of the journals Metabolic Engineering, Biotechnology & Bioengineering and Integrative Biology, and Senior Editor of Biotechnology Journal. He has published over 90 articles and he is co-inventor in three patents and patent applications.

Vassily is a fellow of the American Institute for Medical and Biological Engineering (2010), he was a DuPont Young Professor (2001-2004), and he has also received the Jay Bailey Young Investigator Award in Metabolic Engineering (2000), the ACS Elmar Gaden Award (2011), and the Metabolic Engineering Award from the International Society of Metabolic Engineering (2014).

Keynotes Tuesday

Tuesday 0915-0945, room T2

Parsimonious Cooperative Distributed MPC for Tracking Piece-Wise Constant Setpoints

Matteo Razzanelli, Univ. of Pisa, Italy
***Gabriele Pannocchia**, Univ. of Pisa, Italy*

Tuesday 0915-0945, room T1

Control Loop Performance Monitoring – ABB's Experience Over Two Decades

Kevin Starr, ABB
Margret Bauer, Univ. of the Witwatersrand, South Africa
***Heiko Petersen**, ABB*

Tuesday 0945-1015, room T1

Vinyl Acetate Monomer (VAM) Plant Model : A New Benchmark Problem for Control and Operation Study

***Yuta Machida**, Yokogawa Electric Corp.*
Shigeki Ootakara, Mitsui Chemical Inc.
Hiroya Seki, Tokyo Inst. of Tech.
Yoshihiro Hashimoto, Nagoya Inst. of Tech.
Manabu Kano, Kyoto Univ.
Yasuhiro Miyake, Ube Industries, Ltd.
Naoto Anzai, Zeon Corp.
Masayoshi Sawai, ZEON Corp.
Takashi Katsuno, YOKOGAWA ELECTRIC Corp.
Toshiaki Omata, Yokogawa Electric Corp.

Tuesday 0945-1015, room T2

Operation of an Innovative WWTP with Environmental Objectives. A Model-Based Analysis

***Miguel Mauricio-Iglesias**, Univ. de Santiago de Compostela*
Juan Manuel Garrido, Univ. de Santiago de Compostela
Juan Manuel Lema, Univ. de Santiago de Compostela

Keynotes Wednesday

Wednesday 0915-0945 Room T2

A Multi-Scale Model of the Whole Human Body Based on Dynamic Parsimonious Flux Balance Analysis

Masood Khaksar Toroghi, Univ. of Toronto
William Cluett, Univ. of Toronto
***Radhakrishnan Mahadevan**, Univ. of Toronto*

Wednesday 0915-0945, Room T1

Stability of Multi-Phase Systems Evolving on an Equilibrium Manifold

***B. Erik Ydstie**, Professor of Chemical Engineering, Carnegie Mellon, USA*

Wednesday 0945-1015, Room T1

Dynamic Time to Surge Computation for Electric Driven Gas Compressors During Voltage Dips

***Andrea Cortinovis**, ABB Switzerland Ltd.*
Mehmet Mercangöz, ABB Switzerland Ltd.
Tor Olav Stava, GASSCO AS
Sture Van de Moortel, ABB Switzerland Ltd.
Erling Lunde, Statoil ASA

Wednesday 0945-1015, Room T2

Pointwise Innovation-based State Observation of Exothermic Tubular Reactors

***Alexander Schaum**, Christian-Albrechts Univ. zu Kiel*
Jesus Alvarez, Univ. Autonoma Metropolitana
Thomas Meurer, Christian-Albrechts-Univ. zu Kiel
Jaime A. Moreno, Univ. Nacional Autonoma de Mexico-UNAM

Book of Abstracts

Technical Program for Monday June 6, 2016

MoPL Room T1

Plenary I Manfred Morari: "Process Control and Beyond" (Plenary Session)

Chair: Skogestad, Sigurd — Norwegian Univ. of Science & Tech. (NTNU)

Co-Chair: Budman, Hector M. — Univ. of Waterloo

09:00-09:55 MoPL.1

*Process Control and Beyond**

Morari, Manfred — ETH Zurich

Reflecting on our work over the last 40 years I found that it was dominated by two themes: Computation and Uncertainty. I will describe how the rapidly increasing computational resources have affected our approaches to deal with uncertainty in feedback control. The talk will be illustrated by examples from process control and other application areas like automotive and power systems.

MoA1 Room T3

Performance and Fault Monitoring I (Regular Session)

Chair: Tulsyan, Aditya — Massachusetts Inst. of Tech

Co-Chair: Bollas, George — Univ. of Connecticut

10:30-10:50 MoA1.1

Reachability-Based Fault Detection Method for Uncertain Chemical Flow Reactors, pp. 1-6

Tulsyan, Aditya — Massachusetts Inst. of Tech

Barton, Paul — Massachusetts Inst. of Tech

We consider the problem of computing reachable sets for continuous-time nonlinear continuous-stirred tank reactors (CSTRs). Existing comparison-based methods yield a conservative enclosure for the reachable set due to the non-quasi-monotonic property for CSTR systems. We use a differential inequalities method for computing interval enclosures of CSTR systems. The method proposed in Scott and Barton [2013] is effective; however, it requires a nontrivial a priori enclosure for the reachable set, which is difficult to construct for CSTR reaction systems. We propose a linear transformation to project the dynamics of the original CSTR system onto a sparse state-space. Exploiting the sparsity, we construct a tight a priori enclosure for CSTR systems. The application of the proposed bounding method in designing a fault detection procedure is discussed, and its efficacy illustrated on an example problem.

10:50-11:10 MoA1.2

Built-In Test Design for Fault Detection and Isolation in an Aircraft Environmental Control System", pp. 7-12

Palmer, Kyle — Univ. of Connecticut

Hale, William — Univ. of Connecticut

Han, Lu — Univ. of Connecticut

Jacobson, Clas — United Tech. Corp

Bollas, George — Univ. of Connecticut

A novel built-in test (BIT) design method for fault detection and isolation (FDI) is presented, in which the test information extracted is maximized using parametric sensitivities derived by a system model. Two case studies are presented to demonstrate this approach. The first test focuses on fouling identification in an aircraft heat exchanger, in the presence of uncertain system inputs. The second example expands this method to a subsystem of an aircraft environmental control system (ECS) to calculate optimal conditions for component FDI.

11:10-11:30 MoA1.3

Isolation of Plant-Wide Faults Using Causality Detection Methods, pp. 13-18

Garcia, Guilherme — UFES

Munaro, Celso Jose — Federal Univ. of Espirito Santo

Isolation of plant-wide faults in large-scale complex systems is particularly challenging. A methodology to detect and isolate faults is proposed, detecting the faulty variables using univariate control charts and the causality information between them to indicate the source. The clustering of faulty variables uses univariate analysis to avoid the smearing effect brought by multivariate analysis. The variable where the fault took place is indicated, handling fault novelties in a very natural manner. The proposed method is discussed and illustrated through its application to the Tennessee Eastman Process and to routine operating data from a thermoelectric power plant

11:30-11:50 MoA1.4

Energy-Based Visualisation of a Counter-Flow Heat Exchanger for the Purpose of Fault Identification, pp. 19-24

Uren, Kenneth Richard — North-West Univ

van Schoor, George — North-West Univ

The need for fault detection and diagnosis (FDD) is becoming increasingly important for industrial processes as the complexity of processes increases. A state space model of a counter-flow heat exchanger is used as a case study to illustrate the usefulness of energy-based FDD. Energy is regarded as a unifying parameter to uniquely describe the state of the heat exchanger under fault conditions of fouling and heat leakage. Both steady state and transient energy-based residuals are proposed for the purpose of FDD. The results indicate that the use of energy-based residuals seems viable and warrant further investigation.

MoA2 Room T1

Advances in Predictive Control (Invited Session)

Chair: Zavala, Victor M. — Univ. of Wisconsin-Madison

Co-Chair: Mesbah, Ali — Univ. of California, Berkeley

Organizer: Mesbah, Ali — Univ. of California, Berkeley

Organizer: Zavala, Victor M. — Univ. of Wisconsin-Madison

10:30-10:50 MoA2.1

Data-Driven Plant-Model Mismatch Quantification in Model Predictive Control (I), pp. 25-30

Wang, Siyun — Univ. of Texas at Austin

Simkoff, Jodie — Univ. of Texas at Austin

Baldea, Michael — Univ. of Texas at Austin

Chiang, Leo — Dow Chemical Company

Castillo, Ivan — Dow Chemical Company

Bindlish, Rahul — Dow Chemical Company

Stanley, David — Dow Chemical Company

In this paper, we present a novel data-driven approach for estimating plant-model mismatch for linear MIMO systems operating under constrained MPC. We begin with analyzing the closed-loop plant data; under the assumption that changes in the active set of constraints of the controller are due to (low frequency) setpoint changes, we separate the data into a finite number of fixed active set (FAS) subsets, each of which features a time-invariant active set of MPC constraints. We establish an explicit relationship relating the magnitude of plant-model mismatch to the autocovariance of the system output in the FAS case, while accounting for changes in the setpoint value. The mismatch estimation problem is then formulated as a global optimization calculation, aimed at minimizing the discrepancy between the autocovariance estimated using this theoretical tool, and the autocovariance of plant outputs computed from operating data for each FAS subset. A chemical process case study is presented to illustrate the effectiveness of the approach.

10:50-11:10 MoA2.2

A Stable and Robust NMPC Strategy with Reduced Models and Nonuniform Grids (I), pp. 31-36

Yu, Mingzhao — Carnegie Mellon Univ

Biegler, Lorenz T. Carnegie Mellon Univ

Reduced process models and nonuniform discretizations of state and control profiles are essential to approximate the discretized DAE system, capture multiple time scales of the state profiles and reduce the size of nonlinear programming (NLP) subproblems that arise in off-line optimal control problems. Both reduced models and non-uniform grids are often dictated by dynamic characteristics, which strongly depend on the system application. For Nonlinear MPC (NMPC), nonuniform grids, which we denote as input and state blocking strategies, generally do not lead to recursive feasibility, a key property for nominal stability that follows directly for NMPC with uniform grids. In this study, we modify the NMPC formulation and show how nominal stability and input-to-state stability (ISS) can still be preserved with input and state blocking. The benefits of this approach are shown on a large-scale NMPC process based on a dynamic bubbling fluidized bed (BFB) model for the separation of CO2 from flue gas. Starting with a plant model from first principles with detailed reaction and transport heat and mass transfer models across three zones, we develop a spatially and temporally reduced nonlinear model for NMPC. With this model we demonstrate that additional input and state blocking lead to smaller NLP subproblems, accurate state profiles, and essentially the same performance as with uniform grids associated with the original NLP subproblem.

11:10-11:30 MoA2.3

A Robust NMPC Scheme for Semi-Batch Polymerization Reactors (I), pp. 37-42

Jang, Hong KAIST
Lee, Jay H. KAIST
Biegler, Lorenz T. Carnegie Mellon Univ

A robust nonlinear model predictive control (NMPC) scheme is proposed for batch processes with multiple types of uncertainties. Recently, economic MPC (eMPC) has attracted significant attention, particularly for batch process control given its flexibility in the cost function while addressing the nonlinear constrained multivariable dynamics seen in most batch processes. However, in the presence of various uncertainties such as parameter errors, external disturbances, and noise, performance of eMPC can deteriorate significantly as it tends to drive the system to limits of constraints. To achieve constraint satisfaction in the presence of common uncertainties, we propose a robust NMPC method based on multi-stage scenarios, state estimation, and back-off constraints. Performance of the proposed robust NMPC scheme is evaluated through an example of anionic propylene oxide polymerization reactor.

11:30-11:50 MoA2.4

New Architectures for Hierarchical Predictive Control (I), pp. 43-48

Zavala, Victor M. Univ. of Wisconsin-Madison

We analyze the structure of the Euler-Lagrange (EL) conditions of a long-horizon optimal control problem. The analysis reveals that the conditions can be solved by using block Gauss-Seidel schemes. We prove that such schemes can be implemented in the primal space by solving sequences of short-horizon optimal control problems. This analysis also reveals that a traditional receding-horizon scheme is equivalent to performing a single Gauss-Seidel sweep. We have also found that we can use adjoint information from a coarse long-horizon problem to construct terminal penalties that correct the policies of the receding-horizon scheme. We observe that this scheme can be interpreted as a hierarchical controller in which a coarse high-level controller transfers long-horizon information to a low-level, short-horizon controller of fine resolution. The results open the door to a new family of hierarchical control architectures that can handle multiple time scales systematically.

11:50-12:10 MoA2.5

Stochastic Model Predictive Control with Integrated Experiment Design for Nonlinear Systems (I), pp. 49-54

Bavdekar, Vinay Univ. of California, Berkeley
Mesbah, Ali Univ. of California, Berkeley

The performance of predictive control strategies often degrades over time due to growing plant-model mismatch. Closed-loop performance restoration typically requires some form of model maintenance to reduce model uncertainty. This paper presents a stochastic predictive control approach with integrated experiment design for nonlinear systems with probabilistic modeling uncertainties. The integration of predictive control with experiment design enables enhancing the information content of closed-loop data for online model adaption. The presented approach considers control-oriented experiment design to ensure adequate model adaptation (in probability) in terms of an admissible control performance level. The stochastic optimal control approach is demonstrated on a continuous bioreactor case study.

MoA3 Room T4

Control and Optimization of Batch Processes (Regular Session)

Chair: Budman, Hector M. Univ. of Waterloo
Co-Chair: Bonvin, Dominique EPFL

10:30-10:50 MoA3.1

DRSM Model for the Optimization and Control of Batch Processes, pp. 55-60

Wang, Zhenyu Tufts Univ
Klebanov, Nikolai Tufts Univ
Georgakis, Christos Tufts Univ

Current Optimization and Model Predictive Control practices for batch processes are implemented using two models, one for determining the optimal trajectories and another identified around those trajectories for control purposes. Here we use the recently developed Dynamic Response Surface Modeling methodology from which the optimal trajectories and the local linear or nonlinear state-space models for control purposes are obtained. Because concentration measurements at each batch run are very infrequent, this might be the most attractive way to obtain a dynamic model for control purposes.

10:50-11:10 MoA3.2

Batch-To-Batch Optimization of Chemical Processes in the Presence of Model-Plant Mismatch Using a Variable Subset of Model Parameters, pp. 61-66

Hille, Rubin Univ. of Waterloo
Budman, Hector M. Univ. of Waterloo

In the presence of model-plant mismatch, a standard “two-step” approach, involving repeated identification and optimization steps, cannot guarantee convergence to the process optimum. Model parameter adaptation can be used for handling model error by correcting for mismatch between predicted and measured cost and constraint gradients while simultaneously satisfying both identification and optimization objectives. However, updating all model parameters at once is often impractical due to estimability and increased sensitivity to noise. This work presents a procedure for selecting, after each run, a particular subset of parameters based on parametric sensitivity of the model output and of cost and constraint gradients. The resulting improvements with respect to previous run-to-run studies are illustrated using a simulated case study of a penicillin fed-batch process.

11:10-11:30 MoA3.3

A Novel Algorithm for Design of Mixed Energy-Integrated Batch Process Networks, pp. 67-72

Shahane, Parikshit Inst. of Chemical Tech
Jogwar, Sujit Inst. of Chemical Tech

This paper presents a novel algorithm for calculating minimum utility targets for mixed energy integration which combines direct and indirect strategies. Mixed integration offers enhanced heat recovery compared to direct or indirect strategy at the cost of challenging design. The proposed method is based on time-dependent heat cascade analysis and consists of an iterative application of direct and indirect targeting. The present approach overcomes some of the limitations exhibited by the existing methods. The effectiveness of the proposed algorithm is elucidated for a benchmark energy integration problem wherein the achieved external utility consumption is close to the theoretical minimum value.

11:30-11:50	MoA3.4

On the Use of Shape Constraints for State Estimation in Reaction Systems, pp. 73-78

Srinivasan, Sriniketh	EPFL
Dhurvas, Darsha Kumar	Indian Inst. of Tech. Madras
Billeter, Julien	EPFL
Narasimhan, Shankar	Indian Inst. of Tech. Madras
Bonvin, Dominique	EPFL

State estimation techniques are used for improving the quality of measured signals and for reconstructing unmeasured quantities. In chemical reaction systems, nonlinear estimators are often used to improve the quality of estimated concentrations. These nonlinear estimators, which include the extended Kalman filter, the receding-horizon nonlinear Kalman filter and the moving-horizon estimator, use a state-space representation in terms of concentrations. An alternative to the representation of chemical reaction systems in terms of concentrations consists in representing these systems in terms of extents. This paper formulates the state estimation problem in terms of extents, which allows imposing additional shape constraints on the sign, monotonicity and concavity/convexity properties of extents. The addition of shape constraints often leads to significantly improved state estimates. A simulated example illustrates the formulation of the state estimation problem in terms of concentrations and extents, and the use of shape constraints.

11:50-12:10	MoA3.5

NCO-Tracking with Changing Set of Active Constraints Using Multiple Solution Models, pp. 79-84

Ebrahim, Taher Sabry ElSayed Gomaa	TU Dortmund
Hernandez, Reinaldo	TU Dortmund
Subramanian, Sankaranarayanan	TU Dortmund
Kalliski, Marc	TU Dortmund
Kraemer, Stefan	INEOS Koeln
Engell, Sebastian	TU Dortmund

Measurement-based optimization schemes can be used to counteract the efect of uncertainty and to drive the process to optimality. Necessary Conditions of Optimality Tracking(NCO-tracking) is a promising scheme which uses the process measurements to update the inputs directly. The limiting assumption for the application of the NCO-tracking scheme is that the set of active constraints does not change from its nominal value under the influence of the uncertainties. This paper presents a scheme that extends the NCO-tracking approach to handle parametric uncertainties that change the set of active constraints. Several solution structures are implemented to cover the whole range of the uncertain parameters. Based on the identifcation of the region of the uncertain parameters, the correct solution model is determined and applied to the process. The applicability of the methodology is shown for the benchmark Williams-Otto semi-batch reactor.

MoA4	Room T2

Bioreactor Process Observers and Optimization (Regular Session)

Chair: Perrier, Michel	Ec. Pol
Co-Chair: Bogaerts, Philippe	Univ. Libre De Bruxelles

10:30-10:50	MoA4.1

Cascade Observer Design for a Class of Nonlinear Uncertain Systems - Application to Bioreactor, pp. 85-90

Hernandez-Gonzalez, Omar	Unicaen Cenidet
Ménard, Tomas	Univ. De Caen
Targui, Boubekeur	Ucbn Greyc Auto Umr 6072, Cnrs
Farza, Mondher	Univ. De Caen, ENSICAEN
M'Saad, Mohammed	GREYC
Astorga Zaragoza, Carlos Manuel	Centro Nacional De Investigación Y Desarrollo Tecnológico

The present work proposes a state observer with a cascade structure for a class of nonlinear systems in the presence of uncertainties in the state equations and an arbitrarily long delay in the output. The first system in the cascade allows to estimate the delayed state while each of the remaining systems is a predictor. Each predictor estimates the state of the preceding one with a prediction horizon equal to a fraction of the time delay in such a way that the state of the last predictor is an estimate of the system actual state. The design of the observer is achieved by assuming a set of conditions under which the ultimate boundedness of the estimation error is established. It is in particular shown that in the absence of uncertainties, the observation error converges exponentially to zero. In the presence of uncertainties, the asymptotic observation error remains in a ball which radius depends on the delay magnitude and can be decreased by appropriately choosing the cascade length and the observer design parameters. The performance of the proposed observer and its main properties are highlighted through a typical bioreactor model.

11:10-11:30	MoA4.3

Multi-Objective Optimal Control Study of Fed-Batch Bio-Reactor, pp. 91-96

Padhiyar, Nitin	Indian Inst. of Tech. Gandhinagar
Patel, Narendra	Vishwakarma Government Engineering Coll. Chandkheda

Evolutionary Algorithms have been successfully applied for offline optimal control problems of fed-batch bio-reactors. In such problems, productivity-yield maximization is carried out by optimizing the transient feed recipe. However, this is usually done for a fixed fed-batch time. The optimum batch time can be computed by solving single objective optimal control problems multiple times with different fed-batch times. Since this approach is quite computationally expensive, we in this work formulate a multi-objective optimization(MOO) problem to find the minimum fed-batch time along with maximizing productivity-yield. Such an MOO approach will result in saving significant computational effort. A single parameter based fast mesh sorting with multi objective differential evolution is used in this work for solving MOO problems. We have considered a case study of optimal control of fed-batch reactor for secreted protein production with volume constraint in this work.

11:30-11:50	MoA4.4

Smooth Extremum-Seeking Control for Fed-Batch Processes, pp. 97-102

Jamilis, Martín	LEICI Inst. La Plata Nationa
Garelli, Fabricio	Univ. of La Plata
De Battista, Hernán	Fundacion Facultad De Ingenieria

Many biotechnological processes have optimal substrate concentrations where a maximum growth rate is achieved. In this work an extremum seeking controller and a gradient estimator are proposed to maximize the growth rate in fed-batch bioprocesses even when the substrate to growth rate map is unknown. Both the controller and estimator are obtained with high order sliding mode algorithms. Stability proofs are given, and tools to tune the algorithms in terms of bounds of the hessian of the map are derived. Simulation results that illustrate the performance of the controller are shown.

11:50-12:10	MoA4.5

Greedy Extremum Seeking Control with Applications to Biochemical Processes, pp. 103-108

Trollberg, Olle	KTH Royal Inst. of Tech
Jacobsen, Elling	KTH Royal Inst. of Tech

Extremum seeking control is a subclass of adaptive control, aimed at steady-state optimization. In this paper we apply ideas from extremum seeking control to optimize the transient performance of processes displaying multiple time-scale behavior. The main motivation is the need to optimize biochemical reactors where the biomass growth is significantly slower than the metabolism and where it is of interest to optimize the substrate conversion during the extended periods of net biomass growth or decay. Essentially, by employing singular perturbations, we design a controller that optimizes the fast boundary layer of the system ensuring that the process output is maintained near its maximum during transients towards the steady-state. Similar to greedy methods in optimization theory, we show that the local optimization of the fast layer under certain conditions will provide convergence to the overall optimal steady-state. In particular, this will apply to the type of biochemical reactors that are of main concern in this paper. The proposed controller is demonstrated by application to a model of the CANON process used for nitrogen removal in wastewater treatment. %As we demonstrate for this process, the greedy extremum seeking controller provides a significantly faster convergence to the optimal steady-state as compared to traditional extremum seeking control.

11:50-12:10 MoA4.6

Staged Microbial Fuel Cells with Periodic Connection of External Resistance, pp. 109-114

Recio Garrido, Didac	Pol. of Montreal
Tartakovsky, Boris	National Res. Council of Canada
Perrier, Michel	Ec. Pol

Reactor staging is widely used in wastewater treatment where treatment norms are achieved by connecting two or more reactors in series. The first reactor operates at high carbon source loads and the last reactor performs the final polishing. Microbial Fuel Cells (MFCs) are bioelectrochemical devices designed for direct electricity production from organic matter. Periodic connection of the MFC external electrical resistance was demonstrated to increase performance. An engineering tool to understand this periodic mode of operation is developed. Effluent quality control can be ensured by developing control strategies able to reject variability in the influent concentration while tracking a desired set-point.

MoB1 Room T2

Process Optimization and Plantwide Control I (Regular Session)

Chair: Bollas, George — Univ. of Connecticut

13:00-13:20 MoB1.1

A Model-Based Framework for Dynamic Optimization in Power Generation Systems, pp. 115-120

Han, Lu	Univ. of Connecticut
Bollas, George	Univ. of Connecticut

Optimization methods can be used to improve the design and operation of batch processes. In this work, we illustrate the application of dynamic simulation and optimization for power generation in chemical-looping combustion systems, carried out in batch reactors. We present a framework for the optimization strategy, in which the objective is to maximize a measure of the energy efficiency, bounded by inequality constraints reflecting the industry standards. Several case studies are used to illustrate the applicability of the present problem formulation to enhance the process performance.

13:20-13:40 MoB1.2

Subset Measurement Selection for Self-Optimizing Control of Tennessee Eastman Process, pp. 121-126

Ye, Lingjian	Ningbo Inst. of Tech. Zhejiang Univ
Cao, Yi	Cranfield Univ
Yuan, Xiaofeng	Zhejiang Univ
Song, Zhi-Huan	Zhejiang Univ

The concept of globally optimal controlled variable selection has recently been proposed to improve self-optimizing control performance of traditional local approaches. However, the associated measurement subset selection problem has not be studied. In this paper, we consider the measurement subset selection problem for globally self-optimizing control (gSOC) of Tennessee Eastman (TE) process. The TE process contains substantial measurements and had been studied for SOC with textcolor{red}{controlled variables selected from individual measurements through exhaustive search.} This process has been revisited with improved performance recently through a retrofit approach of gSOC. To extend the improvement further, the measurement subset selection problem for gSOC is considered in this work and solved through a modification of an existing partially bidirectional branch and bound (PB3) algorithm originally developed for local SOC. The modified PB^3 algorithm efficiently identifies the best measurement candidates among the full set which obtains the globally minimal economic loss. Dynamic simulations are conducted to demonstrate the optimality of proposed results.

13:40-14:00 MoB1.3

Optimal PID Control of Double Integrating Processes, pp. 127-132

Grimholt, Chriss	Norwegian Univ. of Science & Tech. (NTNU)
Skogestad, Sigurd	Norwegian Univ. of Science & Tech. (NTNU)

n this paper we investigate optimal pid control of a double integrating plus delay process and compare with the simc rules. There are many industrial and mechanical systems that have double integrating behaviour. What makes the double integrating process special is that derivative action is actually necessary for stabilization. In control there is generally a trade-off between performance and robustness, so there does not exist a single optimal controller. However, for a given robustness level (here defined in terms of the Ms-value) we can find the optimal controller which minimizes the performance J (here defined as the integrated absolute error (iae)-value for disturbances). Interestingly, the simc-controller pid-controller is almost identical to the optimal pid-controller. This can be seen by comparing the pareto-optimal curve for J as a function of Ms, with the curve found by varying the pid tuning parameter τc.

MoB2 Room T1

Model Based Control I (Regular Session)

Co-Chair: Petit, Nicolas — MINES ParisTech

13:00-13:20 MoB2.1

Robust Optimization of Water-Flooding in Oil Reservoirs Using Risk Management Tools, pp. 133-138

Siraj, Muhammad Mohsin	Eindhoven Univ. of Tech
Van den Hof, Paul M.J.	Eindhoven Univ. of Tech
Jansen, Jan Dirk	Delft Univ. of Tech

The theory of risk provides a systematic approach to handling uncertainty with well-defined risk and deviation measures. As the model-based economic optimization of the water-flooding process in oil reservoirs suffers from high levels of uncertainty, the concepts from the theory of risk are highly relevant. In this paper, the main focus is to offer an asymmetric risk management, i.e., to maximize the lower tail (worst cases) of the economic objective function distribution without heavily compromising the upper tail (best cases). Worst-case robust optimization and Conditional Value-at-Risk (CVaR) risk measures are considered with geological uncertainty to improve the worst case(s). Furthermore, a deviation measure, semi-variance, is also used with both geological and economic uncertainty to maximize the lower tail. The geological uncertainty is characterized by an ensemble of geological model realizations and the economic uncertainty is defined by an ensemble of varying oil price scenarios.

13:20-13:40	MoB2.2

Dual Control and Information Gain in Controlling Uncertain Processes, pp. 139-144

La, Huu Chuong	Univ. of Heidelberg
Potschka, Andreas	Univ. of Heidelberg
Schloeder, Johannes P.	Univ. of Heidelberg
Bock, Hans Georg	Univ. of Heidelberg

In controlling uncertain processes, it is decisive to utilize information provided by measurements in order to estimate parameters and states. Nonlinear Model Predictive Control (NMPC) is a popular method to implement feedback control and deal with uncertainties. Conventional NMPC or nominal control, however, sometimes does not provide enough information for system estimation, leading to unsatisfactory performance. Dual control attempts to strike a balance between the two goals of enhancing system estimation and optimizing the nominal objective function. In this paper, we analyze the performance of these strategies through the interplay between the performance control task and the information gain task in connection with Optimal Experimental Design. Examples illustrate the conflict and agreement between the two tasks and explain why in some cases nominal control performs well. It is also observed that measurement noise provides excitation helping to improve the quality of estimates.

13:40-14:00	MoB2.3

Run-To-Run Control with Nonlinearity and Delay Uncertainty, pp. 145-152

Clerget, Charles-Henri	Total RC\Mines ParisTech
Grimaldi, Jean-Philippe	Total RC
Chèbre, Mériam	TOTAL Refining and Marketing
Petit, Nicolas	MINES ParisTech

In this paper, we study a simple single-input single output nonlinear system controlled by a Run-to-run algorithm. Besides the usually considered model uncertainty, the particularity of the system under consideration is that measurements available to the control algorithm suffer from large and varying measurement delays. The control algorithm is a nonlinear sampled model-based controller with successive model inversion and bias correction. The main contribution of this article is its proof of global convergence. In particular, the model error and the varying delays are treated using monotonicity of the system and a detailed analysis of the closed-loop behavior of the sampled dynamics, in an appropriate norm.

MoB3	Room T4

Control Applications in Chromatographic Separation Processes (Regular Session)

Chair: Vande Wouwer, Alain	Univ. De Mons
Co-Chair: Ionescu, Clara	Ghent Univ

13:00-13:20	MoB3.1

Control of Incomplete Separation in Simulated Moving Bed Chromatographic Processes, pp. 153-158

Suvarov, Paul	Univ. De Mons
Vande Wouwer, Alain	Univ. De Mons
Lee, Ju Weon	Max Planck Inst. for Dynamics of Complex Tech. Systems
Seidel-Morgenstern, Andreas	Otto-Von-Guericke Univ
Kienle, Achim	Univ. Magdeburg

Simulated moving bed (SMB) is a continuous chromatographic process used for the separation of fluid mixtures. This paper presents a simple control strategy to handle incomplete separation, which requires tight control to achieve the desired purities. At first, a discrete-time nonlinear model is derived from wave theory, which will be the basis to estimate the position of the adsorption and desorption fronts. Four controllers are designed, two for the position of the concentration waves in zone 1 and 4, and two for the purities at the extract and raffinate outlets. The performance of the control strategy is evaluated with an experimental study of the separation of racemic Bicalutamide enantiomers in a 4 column-SMB.

13:20-13:40	MoB3.2

A Centralized/decentralized Control Approach for Periodic Systems with Application to Chromatographic Separation Processes, pp. 159-164

Papathanasiou, Maria	Imperial Coll. London
Sun, Muxin	Imperial Coll. London
Oberdieck, Richard	Imperial Coll. London
Mantalaris, Athanasios	Imperial Coll. London
Pistikopoulos, Efstratios N.	Texas A&M Univ

In this work we demonstrate the application of our recently presented PAROC framework and software platform for the development of a centralized/decentralized control strategy for the twin-column Multicolumn Solvent Gradient Purification Process (MCSGP) based on multi-parametric control policies. The derived controllers are tested under the presence of disturbances, while their stability is also assessed. The proposed control approach is evaluated under an in-silico, 'closed-loop' fashion against the process model. The designed controller captures efficiently the process setpoints, assuring optimal and stable operation during continuous mode.

13:40-14:00	MoB3.3

An Optimization-Driven Novel Operation of Simulated Moving Bed Chromatographic Separation, pp. 165-170

S V, Vignesh	IIT Bombay
Hariprasad, K	Univ. of Alberta
Athawale, Pratik	IIT Bombay
Bhartiya, Sharad	IIT Bombay

Improvements of conventional SMB operation, such as in Varicol, Modicon, and Powerfeed, have enhanced SMB performance in the past decade. In this work, we propose a novel strategy that incorporates changing internal flow rates and switching periods periodically to enhance flexibility of operation and simultaneously enhance the purity of key product. This mode of operation, called as a dual switching strategy, has been investigated from a modeling perspective with simulation studies to validate the findings. The study incorporates detailed multi-objective optimization problem formulation focusing on performance metrics such as extract purity, recovery and throughput. Unlike the classical SMB processes, dual switching offers a wider scope with its larger degrees of freedom to mutually enhance purity and concentration of key product without the need for SMB configuration modifications. The results reveal a possible fractionating effect on the product side leading to two different purity fractions. Superior performance over the conventional operation has been validated by comparison with classical operation on an SMBC process for separation of glucose and fructose using Ca++ exchange resin.

MoB4	Room T3

Control Applications I (Regular Session)

Chair: Boiroux, Dimitri	Tech. Univ. of Denmark
Co-Chair: Olivier, Laurentz Eugene	Sasol / Univ. of Pretoria

13:00-13:20	MoB4.1

On the Significance of the Noise Model for the Performance of a Linear MPC in Closed-Loop Operation, pp. 171-176

Hagdrup, Morten	Tech. Univ. of Denmark
Boiroux, Dimitri	Tech. Univ. of Denmark
Mahmoudi, Zeinab	Tech. Univ. of Denmark
Madsen, Henrik	Tech. Univ. of Denmark
Poulsen, Niels Kjølstad	Tech. Univ. of Denmark

Poulsen, Bjarne	Tech. Univ. of Denmark
Jorgensen, John Bagterp	Tech. Univ. of Denmark

This paper discusses the significance of the noise model for the performance of a Model Predictive Controller when operating in closed-loop. The process model is parametrized as a continuous-time (CT) model and the relevant sampled-data filtering and control algorithms are developed. Using CT models typically means less parameters to identify. Systematic tuning of such controllers is discussed. Simulation studies are conducted for linear time-invariant systems showing that choosing a noise model of low order is beneficial for closed-loop performance.

13:20-13:40 MoB4.2

Fault-Tolerant Nonlinear MPC Using Particle Filtering, pp. 177-182

Olivier, Laurentz Eugene	Sasol / Univ. of Pretoria
Craig, Ian	Univ. of Pretoria

A fault-tolerant nonlinear model predictive controller (FT-NMPC) is presented in this paper. State estimates, required by the NMPC, are generated with the use of a particle filter. Faults are identified with the nonlinear generalized likelihood ratio method (NL-GLR), for which a bank of particle filters is used to generate the required fault innovations and covariance matrices. A simulated grinding mill circuit serves as the platform for illustrating the use of this fault detection and isolation (FDI) scheme along with the NMPC. The results indicate that faults can be correctly identified and compensated for in the NMPC framework to achieve optimal performance in the presence of faults.

13:40-14:00 MoB4.3

Optimal Boundary Control of a Contact Thawing Process for Foodstuff, pp. 183-188

Backi, Christoph Josef	Norwegian Univ. of Science & Tech. (NTNU)
Leth, John	Aalborg Univ
Gravdahl, Jan Tommy	Norwegian Univ. of Science & Tech. (NTNU)

In this work an approach for thawing blocks of foodstuff, in particular fish, is introduced. The functional principle is based on plate freezer technology, which has been used in industry for decades. The aim of this work is to describe the temperature dynamics of this thawing process by means of partial differential equations (PDEs) and control the boundary conditions in an optimal way. The PDE describing the temperature dynamics is based on the diffusion equation with state-dependent parameter functions.

MoC1 Room T2

Short Oral Presentations of Posters: Computer Applications in Biology and Biotechnology (Poster Session)

Chair: Smets, Ilse	KU Leuven, Department of Chemical Engineering, CREaS

14:05-14:35 MoC1.1

Sensor Configuration Problem: Application to a Membrane Separation Unit, pp. 189-194

Saltik, Bahadir	Eindhoven Univ. of Tech
Ozkan, Leyla	Eindhoven Univ. of Tech
Weiland, Siep	Eindhoven Univ. of Tech
Van den Hof, Paul M.J.	Eindhoven Univ. of Tech

For high performance model based control applications the state and parameter estimation algorithms are essential. Furthermore the accuracy of the resulting estimates highly depends on what is being measured. In this work we address the output channel selection problem by making use of the degree of observability measures defined by the observability gramians of the associated system and possible different sensor configurations. The observability gramians for large scale and nonlinear first principle models are difficult to compute. Instead the data based approximations, the empirical observability gramians, are constructed. The degree of observability measures are used for comparing the spectral properties of the observability gramians to decide the sensor configuration. The output channel selection procedure is applied to an industrial membrane filtration system.

14:05-14:35 MoC1.2

Chemical Recognition Using the Time-Dependent Cellular Response Profile, pp. 195-199

Chen, Jiao	Changzhou Coll. of Information and Tech
Xu, Kaili	Jiangsu Univ
Pan, Tianhong	Jiangsu Univ
Li, Haoran	Jiangsu Univ
Li, Zhengming	Jiangsu Univ

To distinguish the chemicals on the cellular level, a pattern recognition approach, which uses the time-dependent cellular response profiles (TCRPs), is proposed in this paper. Firstly, the TCRPs is collected from the xCELLigence real time cellular analyzer high throughput (RTCA HT) system. Secondly, based on the traditional cellular toxic-effect evaluation, the dose-response curves is generated from the multi-concentration TCRPs. And then features are extracted from the produced dose-response curves. Thirdly, an improved k-means cluster is used to classify the extracted features. The proposed method can provide a useful solution and a high throughput screening for chemical recognition at the cellular level.

14:05-14:35 MoC1.3

In Silico Cell Cycle Predictor for Mammalian Cell Culture Bioreactor Using Agent-Based Modeling Approach, pp. 200-205

Bayrak, Elif Seyma	Illinois Inst. of Tech
Wang, Tony	Amgen Inc
Jerums, Matt	Amgen
Coufal, Myra	Amgen
Goudar, Chetan	Amgen
Cinar, Ali	Illinois Inst. of Tech
Undey, Cenk	Amgen Inc

An agent-based computational modeling approach was used to develop a model to simulate individual mammalian cell cycle regulation in response to dynamic bioreactor conditions. The model can be used as an in silico cell cycle predictor when provided with data from ongoing bioreactor runs. Rules were developed to regulate the distinct cell cycle events as well as to apply decision-making at the critical cellular checkpoints. The model was constructed and validated using different sets of experimental cell culture conditions with cell culture parameters measured using a flow cytometer and other instrumentation.

14:05-14:35 MoC1.4

On the Applicability of Deterministic Approximations to Model Genetic Circuits, pp. 206-211

Pájaro, Manuel	IIM-CSIC
Alonso, Antonio A.	IIM-CSIC

Theoretical results and simulations support the idea that deterministic models provide an acceptable description only for large numbers of molecules. In the context of GRN, which usually involve a small number of molecules, such arguments might lead to disregard deterministic models as unsuitable representations.

We found, however, strong evidences that justify their use to model self-regulatory genetic circuits, even for small number of molecules. In fact, we show that under some conditions, a stochastic system showing a switching-like behaviour (manifested on a bimodal distribution) nearly coincides with a deterministic counterpart exhibiting bistability. Moreover, and contrary to what it might be expected, we find situations involving large numbers of molecules where the deterministic model results into a poor approximation. The analysis and methods presented are expected to help selecting the most adequate system's representation.

14:05-14:35 MoC1.5

Model Development for Phosphate Recovery from Acidic Wastewater, pp. 212-217

Sbarciog, Mihaela	Univ. of Mons
Vande Wouwer, Alain	Univ. of Mons

This paper presents an original model for calcium phosphate crystallization from acidic wastewater. The model is developed using classical principles of chemistry and population balance modeling. The aim is to further use the model for analysis, control and optimization of the crystallization process for phosphate recovery. The proposed model consists of one population balance equation coupled with four mass balance equations and a set of algebraic equations, which can be easily integrated with Matlab and MatMOL toolbox. The model is validated against PHREEQC, a software for speciation and geochemical calculations.

14:05-14:35 MoC1.6

Optimization of a Microalgae Growth Process in Photobioreactors, pp. 218-223

Ifrim, George Adrian	Dunarea De Jos Univ
Titica, Mariana	Univ. of Nantes
Barbu, Marian	Dunarea De Jos Univ. of Galati
Ceanga, Emil	Univ. Dunarea De Jos
Caraman, Sergiu	Dunarea De Jos Univ

The paper proposes a control structure for the optimization of the microalgae cultivation process in photobioreactors, which uses a performance criterion that includes productivity and light use. A 16th order first principles dynamic model was used in the analysis of the control structure. The main results noted in the paper are the following: the realistic evaluation of the performances of the extremum seeking algorithm, solving the optimization problem; the analysis of two light supply control methods; and the identification of two approaches able to replace the extremum seeking optimizer with a biomass control loop that operates at an optimal setpoint determined with the mathematical model. The results were validated through numerical simulation.

14:05-14:35 MoC1.7

Unmeasured Concentrations and Reaction Rates Estimation in CSTRs, pp. 224-229

Lopez-Caamal, Fernando	Univ. Nacional Autonoma De Mexico-UNAM
Moreno, Jaime A.	Univ. Nacional Autonoma De Mexico-UNAM

In this paper, we focus on continuously stirred tank reactors and present a dynamical system capable of estimating i) unmeasured concentrations exponentially fast and ii) completely unknown reaction rates exactly and in finite-time. Towards this end, this observer requires the (partial) knowledge of the mathematical model, along with the inputs and outputs to the system; furthermore, we require that the number of measured concentrations equals the number of unknown reaction rates.

14:05-14:35 MoC1.8

Dynamic Microorganism Growth Modeling for Shelf Life Prediction : Application to Cooked and Brined Shrimps, pp. 230-235

Diallo, Mamadou Aliou	Univ. Cheikh Anta Diop (Dakar), Mathematics-Informatics Dep
Bogaerts, Philippe	Univ. Libre De Bruxelles

Listeria monocytogenes growth data in cooked and brined shrimps under different storage temperatures (0°C, 5°C, 8°C, 15°C and 25°C) were selected from Combase (Dalgaard and Jørgensen, 2000) to develop a dynamic model for shelf life prediction. Based on a multi-step parameter identification procedure, the Baranyi model was fitted for the growth curves of L. monocytogenes, coupled with the Ratkowsky square root model and a sigmoidal function as secondary models for the temperature dependency of the maximum specific growth rate and the maximum cell density respectively. Uncertainty on the prediction of the global growth model was analyzed and the 95% confidence intervals of the predicted microorganism concentration time profiles were determined. Based on these latter, shelf life estimation was 42-53 days, 9-11 days, 3-4 days at 8°C, 15°C and 25°C respectively according to the upper limit of L. monocytogenes in ready-to-eat products, 100 cfu/g. These results are in agreement with those presented in (Dalgaard and Jørgensen, 2000), which illustrates the shelf life prediction abilities of the proposed dynamic growth model.

14:05-14:35 MoC1.9

Plant Growth Modelling : From Experimental Design to Modelling - the Arabidopsis Experiment, pp. 236-241

Dochain, Denis	Univ. Catholique De Louvain
Maclean, Heather	Univ. Catholique De Louvain

This paper deals with the development and identification of a simple mass balance model for plant growth. Further to previous studies, this paper deals with modeling of growth of Arabidopsis thaliana, for which a detailed experimental design has been performed with the objective to address some of the limitations of the previously developed plant growth models, largely in terms of data availability, while accounting for the practical experimental constraints.

14:05-14:35 MoC1.10

Time-Optimal Control and Parameter Estimation of Diafiltration Processes in the Presence of Membrane Fouling, pp. 242-247

Jelemensky, Martin	Slovak Univ. of Tech. in Bratislava
Klauco, Martin	Slovak Univ. of Tech. in Bratislava
Paulen, Radoslav	TU Dortmund
Lauwers, Joost	Katholieke Univ. Leuven
Logist, Filip	Katholieke Univ. Leuven
Van Impe, Jan F.M.	Katholieke Univ. Leuven
Fikar, Miroslav	Slovak Univ. of Tech. in Bratislava

This paper deals with the time-optimal operation and parameter estimation problem of a general diafiltration process in the presence of fouling. Fouling stands for one of the dominant problems in the membrane separation processes. The dynamic behavior of the fouled membrane is described by a general fouling model taken from literature. An Extended Kalman filter is proposed for the recursive estimation of unknown parameters in the fouling model. A model-based optimal nonlinear controller, whose control law is obtained explicitly via Pontryagin's minimum principle, is coupled with the parameter estimation and subsequently applied in a simulation case study to show benefits of the proposed approach.

MoC2 Room T1

Short Oral Presentations of Posters: Model Based Control (Poster Session)

Chair: Trifkovic, Milana	Univ. of Calgary
Co-Chair: Imsland, Lars	Norwegian Univ. of Science & Tech. (NTNU)

14:05-14:35 MoC2.1

Nonlinear Model Predictive Controller for Kick Attenuation in Managed Pressure Drilling, pp. 248-253

Nandan, Anirudh	Memorial Univ. of Newfoundland
Imtiaz, Syed	Memorial Univ. of Newfoundland

We propose a new design of nonlinear model predictive controller (NMPC) for automatic control of managed pressure drilling (MPD) system. The proposed controller acts in a pressure control mode and tracks bottom-hole-pressure (BHP) set point during normal operations, and automatically switches to a flow control mode in the event of abnormal situations, i.e. gas kick. It contains kick, when it occurs, within certain threshold by the deft use of nonlinear state constraints. We use output feedback control architecture and employ offset-free NMPC algorithm which utilizes recursive-discretization for discretization of the model and use active set method for calculating optimal control output. We demonstrate that the proposed controller is able to track a bottom hole pressure set point and contain influx in the presence of measurement noise and plant model mismatches.

14:05-14:35 MoC2.2

Robust Control for a Multi-Stage Evaporation Plant in the Presence of Uncertainties, pp. 254-259

Nguyen, Philipp — Aalto Univ
Tenno, Robert — Aalto Univ

A Multi Stage Flash evaporation plant is investigated as a partly unknown process represented by structured uncertainties concerning several model parameters. Robust control designs in form of H infinity, loop-shaping and mu controllers are applied to the plant. The control objective has been obtained from previous work, where the optimal operating point has been shown to be in form of a reference liquid level profile throughout all the tanks of the plant. The incorporation of uncertainties and the controller into the generalized plant is done via Linear Fractional Transformations. The nominal as well as robust stability and performance are investigated for the controllers.

14:05-14:35 MoC2.3

Dual Mode MPC for a Concentrated Solar Thermal Power Plant, pp. 260-265

Alsharkawi, Adham — Univ. of Sheffield
Rossiter, J. Anthony — Univ. of Sheffield

A model predictive control strategy for a concentrated solar thermal power plant is proposed. Design of the proposed controller is based on an estimated linear time-invariant state space model around a nominal operating point. The model is estimated directly from input-output data using the subspace identification method and taking into account the frequency response of the plant. Input-output data are obtained from a nonlinear distributed parameter model of a plant rather than the plant itself. Effectiveness of the proposed control strategy in terms of tracking and disturbance rejection is evaluated through two different scenarios created in a nonlinear simulation environment.

14:05-14:35 MoC2.4

Dual MPC with Reinforcement Learning, pp. 266-271

Morinelly, Juan E. — Carnegie Mellon Univ
Ydstie, B. Erik — Carnegie Mellon Univ

An adaptive optimal control algorithm for systems with uncertain dynamics is formulated under a Reinforcement Learning framework. An embedded exploratory component is included explicitly in the objective function of an output feedback receding horizon Model Predictive Control problem. The optimization is formulated as a Quadratically Constrained Quadratic Program and it is solved to $epsilon$-global optimality. The iterative interaction between the action specified by the optimal solution and the approximation of cost functions balances the exploitation of current knowledge and the need for exploration. The proposed method is shown to converge to the optimal policy for a controllable discrete time linear plant with unknown output parameters.

14:05-14:35 MoC2.5

Energy Management of a Microgrid Via Parametric Programming, pp. 272-277

Umeozor, Eva Chinedu — Univ. of Calgary
Trifkovic, Milana — Univ. of Calgary

An energy management system (EMS) for efficient and tractable coordination of distributed energy sources in a residential level microgrid is presented. Sources of energy include renewable (solar photovoltaic and wind turbine), conventional systems (microturbine and utility grid connection) and battery energy storage system. The overall problem is formulated using parametric mixed-integer linear programming (p-MILP) via parameterizations of the uncertain coordinates of the wind and solar resources. This results in a bi-level optimization problem, where choice of the parameterization scheme is made at the upper level while system operation decisions are made at the lower level. The p-MILP formulation leads to significant improvements in uncertainty management, solution quality and computational burden; by easing dependency on meteorological information and avoiding the multiple computational cycles of the traditional online optimization techniques. The problem is solved offline on a day-ahead basis, allowing online implementation to be achieved via real-time system state updates. The proposed parametric programming approach extends the state-of-the-art in microgrid energy management methods, and the simulation evidence its feasibility and effectiveness.

14:05-14:35 MoC2.6

Control of an Exothermic Packed-Bed Tubular Reactor, pp. 278-283

Najera, Israel — Univ. Autónoma Metropolitana-Iztapalapa
Alvarez, Jesus — Univ. Autonoma Metropolitana
Baratti, Roberto — Univ. Degli Studi Di Cagliari
Sotres, César — Univ. Autónoma Metropolitana Unidad Iztapalapa

The problem of robustly controlling a highly exothermic gas-phase packed-bed tubular reactor on the basis of feed and reactor temperature measurements is addressed. First, advanced nonlinear control yields a detailed model-based output feedback (OF) control design with passivity and observability solvability conditions, sensor location criterion, and simple tuning. Then, the behavior of the advanced controller is recovered with a simplified model-based realization that amounts to an industrial temperature tracking controller with feedforward (FF) dynamic setpoint compensation. The advanced and industrial controllers are formally connected. The approach is illustrated and tested with a representative case example through numerical simulations

14:05-14:35 MoC2.7

PID Controller Tuning for Unstable Processes Using a Multiobjective Optimisation Design Procedure, pp. 284-289

Reynoso-Meza, Gilberto — Pontificia Univ. Católica De Paraná
Carrillo-Ahumada, J. — Univ. Del Papaloapan
Boada, Yadira — Univ. Pol. De València
Picó, Jesús — Univ. Pol. De Valencia

Multiobjective optimisation techniques have shown to be a useful tool for controller tuning applications. Such techniques are useful when: 1) it is difficult to find a controller with a desirable trade-off between conflictive objectives and/or 2) it is valuable to extract an additional knowledge from the process by analysing trade-off among possible controllers. In this work, we propose a multiobjective optimisation design procedure for unstable process, using PID controllers. The provided examples show the usability of the procedure for this kind of process, sometimes difficult to control; comparison with existing tuning rule methods provide promising results for this tuning procedure.

14:05-14:35 MoC2.8

Numerical Optimal Control Mixing Collocation with Single Shooting: A Case Study, pp. 290-295

Albert, Anders — Norwegian Univ. of Science & Tech. (NTNU)
Imsland, Lars — Norwegian Univ. of Science & Tech. (NTNU)
Haugen, Joakim — Norwegian Univ. of Science & Tech. (NTNU)

This paper looks into implementation of numerical optimal control problems of systems with a cascade structure, in which only one part of the dynamic equality constraints has path constraints. We consider two dierent direct strategies for numerical implementation using direct methods: 1. Collocation for both parts of the cascade. 2. Direct collocation for one part and single shooting for the other. To compare the methods we study the case of iceberg monitoring using a single unmanned aerial vehicle. The study reveals that second method under some conditions can be more computationally ecient

MoC3 Room T3

Short Oral Presentations of Posters: Modelling and System Identification (Poster Session)

Chair: McAuley, K.B. — Queen's Univ

Co-Chair: Lee, Jong Min — Seoul National Univ

14:05-14:35 MoC3.1

Robust Automatic Choke Control – Physical Constraint Based Operation, pp. 296-301

Kittilsen, Pål — Statoil ASA

Fjalestad, Kjetil — Statoil ASA

Sperle, Ingvild Løvik — Statoil R&D

Aasheim, Robert — Statoil ASA

Process fluctuations are often equivalent to lost production as the necessary margins to process constraints need to take into account the fluctuations. Better operation is achieved by reduced process fluctuations enabling operation closer to the constraints (reducing the backoff) thus the average production increases. For oil wells, this transition is typically achieved with automatic choke control.

Both oil and gas production wells and injection wells benefit from automatic choke control. The natural variations of the underlying process require frequent adjustments of the well chokes in order to keep key parameters at their optimal values. If not operating the choke at fully open position, it is normally beneficial to replace manual operation with automatic choke control. This approach enables operation close to active well constraints. In addition, automatic actions can be taken to avoid safety issues.

This paper gives practical examples of the benefits obtained by applying automatic choke control to gas coning wells and water injectors. Exchanging manual infrequent choke manipulations with continuous operations close to the true, physical constraints, enable safe and optimal production

14:05-14:35 MoC3.2

Control of Reversible Degradation Mechanisms in Fuel Cells: Mitigation of CO Contamination, pp. 302-307

Tjønnås, Johannes — SINTEF

Zenith, Federico — SINTEF

Halvorsen, Ivar J. — SINTEF

Klages, Merle — Zentrum Für Sonnenenergie Und Wasserstoff-Forschung BW (ZSW)

Scholta, Joachim — Zentrum Für Sonnenenergie Und Wasserstoff-Forschung BW (ZSW)

Fuel Cells are subject to several degradation phenomena where some are reversible and some irreversible. Normally all contribute to a reduced cell voltage, but it may be complicated to discriminate the particular causes. A brief overview is given and a method for modelling and controlling the particular case of CO contamination by use of active and adaptive air-bleed manipulation is presented.

14:05-14:35 MoC3.3

Evaluation of Experiment Designs for MIMO Identification by Cross-Validation, pp. 308-313

Häggblom, Kurt-Erik — Åbo Akademi Univ

Guidelines for design of input perturbations for identification of multivariable systems are given. The focus is on control-oriented identification, but for comparison some general-purpose designs are also considered. The information needed for design of input perturbations such as double rectangular pulses, pseudo-random binary sequences, and multi-sinusoidal signals can be obtained from a simple step test. Such a test also gives information about the directionality properties of the system. This information can be used to design control-oriented experiments as shown in the paper. The design techniques are illustrated by realistic simulations of a moderately ill-conditioned 3x3 system. The identified models, and thus the experiment designs, are evaluated by cross-validations. According to this evaluation, the directional input designs are superior to standard input designs for identification of MIMO systems.

14:05-14:35 MoC3.4

Energy-Based Visualisation of an Axial-Flow Compressor System for the Purposes of Fault Detection and Diagnosis, pp. 314-319

Fouché, Lourie — North-West Univ

Uren, Kenneth Richard — North-West Univ

van Schoor, George — North-West Univ

As the complexity of industrial systems increases, the necessity also increases for more reliable, robust and accurate Fault Detection and Diagnosis (FDD) techniques. This article proposes a methodology for the design of an FDD system, based on an energy visualisation of an axial-flow compressor system. This method investigates the steady state and transients of the system for residual generation. A nonlinear model is derived for this compressor system that are capable of modelling compressor instabilities such as rotating stall, surge and leaks. A power-energy analysis is done using the state variables of the system under normal and fault conditions and are visually presented. Two fault conditions are analysed in terms of power and energy. The first test case introduces a leak in the system. The second focuses on the more complex situation when the system enters an unstable operation, namely rotating stall. The results indicate that the power and energy of the system may be useful for the purposes of FDD.

14:05-14:35 MoC3.5

Fundamental Modeling and Experimental Investigation of Polymer Washing Process, pp. 320-325

Son, Sang Hwan — Seoul National Univ

Jeong, Dong Hwi — Seoul National Univ

Ryu, Hyun Woog — LG Chem

Han, Joong Jin — LG Chem

Lee, Jong Min — Seoul National Univ

After polymerization reaction, impurities such as adduct, solvent and catalyst are trapped inside the polymers. These impurities should be removed by a polymer washing process to improve the purity of the polymer products. Also, the optimization of the polymer washing process is essential to reduce the energy, resources and processing time. This work provides theoretical basis for optimization of polymer washing process by proposing a fundamental model and experimental investigation method of the process. The model describes the impurity distribution inside the polymers, mole balance of impurities inside and outside of the polymers, and impurity diffusion rate at polymer surface. The experimental investigation with SPAEK (sulfonated poly(aryl ether ketone)) samples reports the impurity diffusion coefficient at polymer surface of the performed experiments. The computed D shows different values with time and operation condition, as a lumped parameter. However, these values show the same trajectory with the introduction of a dimensionless number Co for each operation. This means the other impurity diffusion factors embraced in D are only affected by Co. Finally, we validate the prediction performance of the model by comparing the predicted pH changes of validation experiment with the experimental data.

14:05-14:35 MoC3.6

Modelling Combined LNT-Pscr System and Sensitivity Analysis, pp. 326-331

Kim, Yeonsoo — Seoul National Univ

Jung, Changho — Hyundai Motor Company

Kim, Chang Hwan — Hyundai Motor Company

Kim, Yong-Wha — Hyundai Motor Company

Lee, Jong Min — Seoul National Univ

The nitrogen oxides (NOx) emitted from diesel engines become major issues. Exhausted gas recirculation (EGR), lean NOx trap

(LNT), and selective catalytic reduction (SCR) are typical methods to reduce the NOx emission. With LNT-pSCR system, the performance can be improved and the occupied space can be reduced. In this paper, a modified dynamic model for LNT-pSCR system is constructed. Sensitivity analysis is also performed with the simulation result. It is shown that the proposed model is consistent with the existing studies and parameters related to mass balances have a priority to those related to energy balance in parameter estimation to simulate the total dynamic system.

14:05-14:35 MoC3.7

Agile Control of CO2 Capture Technology for Maximum Operations Revenue, pp. 332-335

Abdul Manaf, Norhuda	Univ. of Sydney
Qadir, Abdul	Univ. of Sydney
Abbas, Ali	Univ. of Sydney

This paper uses a multi-layered control scheme consisting of model predictive control (MPC) and mixed integer non-linear programming (MINLP) for the analysis of power plant net operating revenue when retrofitted with a post-combustion carbon capture (PCC) plant. The capability of the proposed control scheme is examined for 24-hour operations of an integrated plant (power plant with PCC) in the years 2011 and 2020. The control scheme is tested in response to variability in upstream power plant dynamic loads. The agility of the control scheme subject to forecast 2020 electricity and carbon prices is shown to result in yearly net operating revenue of approximately 12% of the gross revenue. Whereas, the same integrated plant generates a net operating revenue loss of roughly 13% of the gross revenue under 2011 electricity and carbon prices.

MoC4 Room T4

Short Oral Presentations of Posters: Control Applications/Fault Detection (Poster Session)

Chair: Palazoglu, Ahmet N. Univ. of California at Davis

14:05-14:35 MoC4.1

Handling of Variable Wireless Latency and Updating Frequency in PI Controllers, pp. 336-341

Halvorsen, Ivar J.	SINTEF

In closed loop process control with wireless measurements it must be ensured that communication packet dropouts and variable latency is handled properly with respect to the impact on the controlled process. A procedure for automatic adjustment of the controller parameters is presented. The main property is to maintain the closed loop stability margin in presence of variable communication latency. The sampling rates in wireless instrumentation are usually chosen to be quite slow to save battery power in the transmitters, so both selecting the appropriate sampling rates and handling of the real transmission characteristics in a closed loop process control environment require attention. The presented algorithm can handle typical wireless communication errors, and can also be used to deliberately alter the sampling rate based on the actual disturbance level and by that save battery power in calm periods. The algorithm is based on the SIMC tuning rules.

14:05-14:35 MoC4.2

Design of a Data-Driven Controller for a Spiral Heat Exchanger, pp. 342-346

Wakitani, Shin	Tokyo Univ. of Agriculture and Tech
Deng, Mingcong	Tokyo Univ. of Agriculture and Tech
Yamamoto, Toru	Hiroshima Univ

A data-driven proportional-integral-derivative (DD-PID) controller has been proposed as an effective controller for nonlinear systems. The DD-PID controller can tune the PID parameters adaptively at each equilibrium point. In order to train the PID parameters in a database, an offline learning algorithm based on a fictitious reference iterative tuning (FRIT) method was established. This method can compute the PID parameters by using a set of operating data. However, the FRIT method is a control parameter tuning method that is only based on the minimization of the system output in its criterion; therefore, the criterion is insufficient for systems in which the stability of a closed-loop system is important such as chemical process systems because sometimes the sensitivity of an obtained controller becomes high. In order to solve this problem, an extended FRIT (E-FRIT) method that penalizes the input variation in its criterion has been proposed. In this method, the PID parameters that are taken into stability can be calculated. The effectiveness of the proposed method is evaluated by an experimental result of a spiral heat exchanger.

14:05-14:35 MoC4.3

Active Compressor Surge Control System by Using Piston Actuation: Implementation and Experimental Results, pp. 347-352

Uddin, Nur	Norwegian Univ. of Science & Tech. (NTNU)
Gravdahl, Jan Tommy	Norwegian Univ. of Science & Tech. (NTNU)

A novel implementation and experimental test results of a piston actuated active surge control system (PAASCS) on a laboratory scale pipeline-compressor system are presented. The experimental test is done to prove the concept of stabilizing compressor surge by dissipating the plenum energy using a piston actuation. The PAASCS's controller is applying psi-control introduced in (Uddin and Gravdahl, 2016), which only uses feedback from pressure measurements at the compressor discharge and in the plenum. Practical aspects of implementing the PAASCS are presented including: flow measurement, generating a compressor map based on a compressor performance test, piston design, and the test setup. The experimental test results show that the PAASCS is able to stabilize surge and prove the concept of PAASCS with the advantage of psi-control.

14:05-14:35 MoC4.4

Energy-Based Fault Detection for an Autothermal Reformer, pp. 353-358

Marais, Henri-Jean	North-West Univ
van Schoor, George	North-West Univ
Uren, Kenneth Richard	North-West Univ

Condition monitoring has traditionally been deployed for the monitoring of a single component, such as a rotating machine. The application of condition monitoring techniques to entire petrochemical process plants, however, remains lacking. This can be ascribed to the signicant complexity involved in applying existing techniques to such plants. In this work a novel energy-based fault detection scheme is applied to an autothermal reformer of a gas-to-liquids process. The performance of the technique is evaluated, against a set of representative faults, and it is shown to provide adequate fault detection performance. The use of the energy-based detection scheme shows promise in terms of reduced modelling eorts and increased computational eciency.

14:05-14:35 MoC4.5

Sensitivity Based Optimization of the Tri-Reforming Based CO_2 Valorization Process, pp. 359-364

Dwivedi, Abhishek	IIT Bombay
Gudi, Ravindra	IIT Bombay
Biswas, Pratim	Washington Univ. St Louis

Rising CO_2 levels in the atmosphere has been a serious concern and threat to the environment. Thus mitigation of CO_2 becomes really important. To achieve the same, a relatively new approach of tri-reforming process is studied in this paper. Taking waste flue gases as a source of CO_2 and methane as a co-feed, a process flow sheet has been developed that converts the above mentioned two species to methanol. In this study we consider the conversion of flue gases and methane into methanol via three steps namely the tri-reforming process, a water separation system and methanol production process. The water separation system used in

conjunction with the other two processes is a novel aspect of our approach and it demonstrates the importance of water removal in terms of the overall flow sheet improvement. The improved process delivers an improved product yield of 3.12 times the original tri-reforming coupled methanol production process. The developed process flow sheet is simulated and optimized in Aspen Plus V8.4 and various sensitivity studies have been performed that illustrate the feasibility of the proposed approach. Moreover an effective multiple stage methanol production process is suggested for CO_2 rich synthesis gas generated by tri-reforming or otherwise.

14:05-14:35 MoC4.6

Effect of Sampling Rate on the Divergence of the Extended Kalman Filter for a Continuous Polymerization Reactor in Comparison with Particle Filtering, pp. 365-370

Hashemi, Reza TU Dortmund
Engell, Sebastian TU Dortmund

The Extended Kalman Filter (EKF) is the most widely used state estimation technique for non-linear systems in the field of process engineering. In this contribution, we investigate the performance of the EKF for continuous polymerization of acrylic acid in a tubular reactor with multiple side feeds of monomer. The EKF usually yields satisfactory estimations if the nonlinearities of the underlying system are not too severe. We observed that the EKF for this process diverges regardless of its tuning unless it is iterated at very fast sampling rates. In order to verify this, we have tested the EKF for different tunings and different sampling rates in 100 independent Monte Carlo simulations for each setup. In contrast Particle Filters use the nonlinear model of the process directly and do not suffer from the problems caused by linearization. On the other hand the computation times are significantly higher.

14:05-14:35 MoC4.7

Practical Use of Savitzky-Golay Filtering-Based Ensemble Online SVR, pp. 371-376

Kaneko, Hiromasa Univ. of Tokyo
Matsumoto, Takuya Mitsui Chemicals, Inc
Ootakara, Shigeki Mitsui Chemical Inc
Funatsu, Kimito Univ. of Tokyo

As a result of collaboration between Mitsui Chemicals, Inc. and the University of Tokyo, a soft sensor tool was developed and implemented in several plants in Mitsui Chemicals, Inc. A soft sensor is an inferential model constructed between process variables that are easy to measure (X) and process variables that are difficult to measure (y). y-values can be estimated in real time by inputting X-values into a soft sensor. To maintain predictive ability of a soft sensor to be high, we employ ensemble online support vector regression (EOSVR) model as an adaptive soft sensor model, which can adapt to both nonlinear changes and time-varying changes. Additionally, to reduce noise in estimated y-values, Savitzky-Golay (SG) filtering is used for estimated y-values. Our proposed method is called EOSVR-SG and implemented as a soft sensor tool. In this paper, we show our soft sensor tool used in real chemical plants and its execution results in which the EOSVR-SG model could estimate y-values accurately and smoothly.

14:05-14:35 MoC4.8

Variability Reduction Estimation for SISO Systems through Unmeasured Disturbance Estimation, pp. 377-382

Lima, Maria Federal Univ. of Rio Grande Do Sul
Trierweiler, Jorge Otávio Federal Univ. of Rio Grande Do Sul
Farenzena, Marcelo Federal Univ. of Rio Grande Do Sul

The variability within a process can be seen as a limiting factor for its efficiency. Because this, the present paper provides a simple, fast and non-intrusive methodology, able to translate the part in total variability that can be changed through controller adjustment. These types of analyses are usually intrusive; however, this work presents an alternative to obtaining such information from non-intrusive manner, thus eliminating a need for system perturbation. It is proposed to estimate the variability reduction through a sequential method that uses unmeasured disturbance estimation and a representative model of the actual process. The method's quality was tested by analyzing the sensitivity of methodology against several initial conditions, since the procedure requires an optimization step. The case studies that involved pure time delay have showed high sensitivity to the initial condition, but even in this case the potential for variability reduction was correctly estimated.

14:05-14:35 MoC4.9

Variable Elimination-Based Contribution for Accurate Fault Identification, pp. 383-388

Satoyama, Yusuke Kyoto Univ
Fujiwara, Koichi Kyoto Univ
Kano, Manabu Kyoto Univ

We propose a new fault identification method, which can describe the contribution of each process variable to a detected fault and identify a faulty variable more accurately than conventional methods. In the proposed method, in addition to a fault detection model that describes normal operating condition (NOC), multiple fault identification models that describe the same NOC are also constructed by eliminating one variable from all monitored variables at a time. After a fault is detected with the fault detection model, the fault detection index, e.g. a combined index of the T^2 and Q statistics, is calculated by using each of the fault identification models. When the faulty variable is eliminated, the index does not change before and after the fault occurs. On the other hand, when the normal variable is eliminated, the index is affected by the fault and increases after the fault occurs. Thus, the eliminated variable corresponding to the index that does not increase after the occurrence of the fault is identified as a faulty variable. In the proposed method, the ratio of the average index in NOC to the current index is used as a fault identification index or a contribution. To validate the proposed method, VEC was compared with the reconstruction-based contribution (RBC) through numerical examples. The results have demonstrated that VEC outperformed RBC in fault identification performance both in the linear case and in the nonlinear case.

14:05-14:35 MoC4.10

Reducing Wear of Sticky Pneumatic Control Valves Using Compensation Pulses with Variable Amplitude, pp. 389-393

Munaro, Celso Jose Univ. Federal Do Espírito Santo
Castro, Gabriel Petróleo Brasileiro S.A
Silva, Filipe Univ. Federal Do Espírito Santo
Becerra Angarita, Oscar Fernando Univ. Federal Do Espírito Santo
Cypriano, Marcos Vinicius Gomes Univ. Federal Do Espírito Santo

The presence of friction in control valves produces limit cycles that reduces the performance of control loops. Once friction is detected, its compensation avoids process stops until the next maintenance stop is performed. Model free methods adding feed-forward pulses to PID controller output have been proposed to reduce the effect of friction. A common drawback in such methods is the increase in the movement of the valve stem. A new method is here proposed to overcome this issue. The amplitude of the pulses vary and becomes zero when a specified limit for the error on the process variable is achieved. Another advantage of this method is its ability to cope with uncertainty in friction, since the amplitude of the pulses pulses vary between limits. The method is illustrated via simulation, and its implementation in a real industrial controller is shown and discussed.

14:05-14:35 MoC4.11

Fault Detection for Simulated Valve Faults in a High Pressure Leaching Process, pp. 394-399

Miskin, Jason John Stellenbosch Univ
Lindner, Brian Stellenbosch Univ
Auret, Lidia Stellenbosch Univ
Dorfling, Christie Stellenbosch Univ

Bradshaw, Steven — Stellenbosch Univ

A simulation of a high pressure leaching process in a base metals refinery (BMR) is used to simulate fault conditions for two types of valve faults. The faults were modelled using empirical models fitted to actual process data from Western Platinum Ltd. BMR. The effects of the faults on process performance were determined. Following this, principal component analysis (PCA) was used to determine whether these faults could be detected. It was found that both faults had a significant effect on control performance, and that PCA was able to detect both faults accurately.

MoD1 — Room T1

Process Optimization and Plantwide Control II (Regular Session)

Chair: Foss, Bjarne — Norwegian Univ. of Science & Tech. (NTNU)

Co-Chair: Swartz, Christopher L.E. — McMaster Univ

15:50-16:10 — MoD1.1

Spline Fluid Models for Optimization, pp. 400-405

Jahanshahi, Esmaeil — Norwegian Univ. of Science & Tech. (NTNU)

Grimstad, Bjarne — Norwegian Univ. of Science & Tech. (NTNU)

Foss, Bjarne — Norwegian Univ. of Science & Tech. (NTNU)

Oil production optimization is usually formulated by applying mass and momentum balances of the production network. By including temperature as a variable in pipe pressure drop, pump, and compressor models one may improve their accuracy, as well as the accuracy of the overall production system model. In addition, it is sometimes desirable to add temperature constraints to avoid flow assurance issues (emph{e.g.} wax and gas hydrates). The introduction of temperatures in the optimization problem requires thermodynamic properties of the fluid as functions of pressure and temperature. In this paper, a unifying fluid model for optimization using B-splines is presented. The fluid model can be constructed based on a Black-Oil model or from PVT simulations. The B-spline has properties that make it suitable for optimization. The applicability of the method is demonstrated in two examples, and the results are compared with realistic Olga simulator output.

16:10-16:30 — MoD1.2

Closed-Loop Formulation for Nonlinear Dynamic Real-Time Optimization, pp. 406-411

Jamaludin, Mohammad Zamry — McMaster Univ

Swartz, Christopher L.E. — McMaster Univ

Dynamic real-time optimization (DRTO) is a higher level online strategy that exploits plant economic potential by making appropriate adjustments to the lower level controller set-point trajectories. In this work, we propose a closed-loop formulation for a nonlinear DRTO calculation in the form of a bilevel programming problem. A nonlinear differential algebraic equation (DAE) system that describes the process dynamic behavior is utilized with an embedded constrained predictive control (MPC) optimization subproblem to generate the approximate closed-loop response dynamics at the primary economic optimization layer. The bilevel DRTO problem is reformulated as a single-level mathematical program with complementarity constraints (MPCC) by replacing the MPC optimization subproblem by its Karush-Kuhn-Tucker (KKT) optimality conditions. We investigate the economics and control performance of the proposed strategy based on a polymer grade transition case study in the presence of plant-model mismatch and a disturbance, and a comparison is made with the application of a linear DRTO prediction model.

16:30-16:50 — MoD1.3

Real-Time Optimization Based on Adaptation of Surrogate Models, pp. 412-417

Singhal, Martand — EPFL

Marchetti, Alejandro Gabriel — EPFL

Faulwasser, Timm — EPFL

Bonvin, Dominique — EPFL

Recently, different real-time optimization (RTO) schemes that guarantee feasibility of all RTO iterates and monotonic convergence to the optimal plant operating point have been proposed. However, simulations reveal that these schemes converge very slowly to the plant optimum, which may be prohibitive in applications. This note proposes an RTO scheme based on second-order surrogate models of the objective and the constraints, which enforces feasibility of all RTO iterates, i.e., plant constraints are satisfied at all iterations. In order to speed up convergence, we suggest an online adaptation strategy of the surrogate models that is based on trust-region ideas. The efficacy of the proposed RTO scheme is demonstrated in simulations via both a numerical example and the steady-state optimization of the Williams-Otto reactor.

16:50-17:10 — MoD1.4

Null-Space Method for Optimal Operation of Transient Processes, pp. 418-423

de Oliveira, Vinicius — Norwegian Univ. of Science & Tech. (NTNU)

Jäschke, Johannes — Norwegian Univ. of Science & Tech. (NTNU)

Skogestad, Sigurd — Norwegian Univ. of Science & Tech. (NTNU)

We consider batch process optimization and robust implementation of optimal control policies. The dynamic optimization of such processes is in most cases model based, and therefore subject to uncertainties. This may lead to sub-optimal control trajectories with significant economical losses. In this paper we extended the concept of self-optimizing control for the optimal operation of transient processes. The main idea is to find a function of the measurements whose trajectory is optimally invariant to disturbances, and then track the trajectory using standard feedback controllers. Doing so results in near-optimal economic operation in spite of varying disturbances without the need for re-optimization. We show that the invariant trajectories can be computed as linear combinations of the measurement vector, where the combination matrix is easily obtained from optimal sensitivities. We illustrate the application of the proposed method in a semi-batch reactor case study.

17:10-17:30 — MoD1.5

Performance Improvement of Extremum Seeking Control Using Recursive Least Square Estimation with Forgetting Factor, pp. 424-429

Chioua, Moncef — ABB Corp. Res. Germany

Srinivasan, B. — Ec. Pol. Montreal

Guay, Martin — Queen's Univ

Perrier, Michel — Ec. Pol

The main limitation of perturbation based extremum seeking methods is the requirement of a multiple time-scale separation between the system dynamics, the perturbation frequency, and the adaptation rate so as to avoid interactions and possible instabilities. This causes the convergence to be extremely slow. In the present work, we propose a simple modification to the perturbation-based extremum seeking control method that can be used when the system cannot be accurately approximated by a Wiener Hammerstein model for which convergence rate acceleration schemes are available. The linear filtering used in the perturbation based extremum seeking control for estimating the objective function gradient is replaced by a recursive least square with forgetting factor estimation algorithm. It is shown that this simple modification can accelerate convergence to the optimum by removing one time scale separation.

MoD2 — Room T3

Micro and Nanotechnology Applications (Invited Session)

Chair: Ricardez-Sandoval, Luis Alberto	Univ. of Waterloo
Co-Chair: Adomaitis, Raymond	Univ. of Maryland
Organizer: Ricardez-Sandoval, Luis Alberto	Univ. of Waterloo

15:50-16:10 MoD2.1

Markov Decision Process Based Time-Varying Optimal Control for Colloidal Self-Assembly (I), pp. 430-435

Tang, Xun	Georgia Inst. of Tech
Bevan, Michael	Johns Hopkins Univ
Grover, Martha	Georgia Inst. of Tech

Crystals made of periodically well-ordered nano- and/or micro-scale elements can interact with light to give novel properties. These perfect crystals have applications in a wide range of areas. For example, invisibility cloaks that reroute light transmission make objects disappear. However, manufacturing such perfect crystals still remains challenging. Here, we propose a low-dimensional Markov decision process based dynamic programming framework to optimally control a colloidal self-assembly process for perfect crystal fabrication. Based on the simulation results, we demonstrate that an open-loop control policy identified with the proposed framework is able to reduce the defective assemblies from 46% of uncontrolled to 8% of controlled production. Moreover, when feedback is available, a closed-loop optimal finite-horizon control policy can further reduce the defective assemblies down to 5% out of 100 independent simulation runs.

16:10-16:30 MoD2.2

Distributional Uncertainty Analysis in Transient Heterogeneous Multiscale Catalytic Flow Reactors (I), pp. 436-441

Chaffart, Donovan R. G.	Univ. of Waterloo
Ricardez-Sandoval, Luis Alberto	Univ. of Waterloo

This work explores the effects of parameter uncertainty and model-plant mismatch on a transient, spatially heterogeneous multiscale catalytic reactor system. Uncertainty in key system parameters is propagated into the concentration of the reactor product species using power series expansion (PSE). The reactor model is constructed through the combination of continuum equation modeling, to describe mass transport within the reactor, with kinetic Monte Carlo (kMC) simulations that predicts the behavior of the catalyst surface. The uncertainty analysis illustrated in this study is employed to evaluate the effects of uncertainty on the reactor product concentration as it evolves in time and space.

16:30-16:50 MoD2.3

Mathematical Modeling and Analysis of Carbon Nanotube Photovoltaic Systems (I), pp. 442-447

Paulson, Joel	Massachusetts Inst. of Tech
Molaro, Mark C.	Massachusetts Inst. of Tech
Bellisario, Darin O.	Massachusetts Inst. of Tech
Strano, Michael S.	Massachusetts Inst. of Tech
Braatz, Richard D.	Massachusetts Inst. of Tech

This article considers first-principles predictive modeling of carbon nanotube photovoltaic (PV) devices, with the objective being to increase predictive capabilities to the point that systems engineering approaches can be applied. After covering some background, the state of the art in first-principles modeling is reviewed and extended to include the construction of realistic spatial placements of carbon nanotubes within the device during manufacturing and the effects of exciton hopping between carbon nanotubes. Challenges in the construction of improved first-principles models and some promising future directions are discussed.

16:50-17:10 MoD2.4

Dynamic Dimension Reduction for Thin-Film Deposition Reaction Network Models (I), pp. 448-453

Adomaitis, Raymond	Univ. of Maryland

A prototype thin-film deposition model is developed and subsequently used in a sequence of model reduction procedures, ultimately reducing the dynamic dimension from six to one with essentially no loss in accuracy to the dynamics of the deposition process. The species balance model consists of a singular perturbation problem of nonstandard form which first is numerically solved following the approach of Daoutidis (2015). An alternative strategy then is presented, consisting of a reaction factorization procedure which facilitates the solution of the outer solution of the singular perturbation problem and provides unique physical insight into the conserved quantities identified by the elimination of redundant dynamic modes. Further reduction in dynamic dimension then is achieved through a second factorization focused only on the major reaction species. This second reduction procedure identifies pseudo-equilibria of finite-rate properties and introduces an additional level of complexity to the challenges of identifying consistent initial conditions for DAE systems.

17:10-17:30 MoD2.5

A Transfer Entropy Method to Quantify Causality in Stochastic Nonlinear Systems, pp. 454-459

Gao, Jiaqi	Tsinghua Univ
Tulsyan, Aditya	Massachusetts Inst. of Tech
Yang, Fan	Tsinghua Univ
Gopaluni, Bhushan	Univ. of British Columbia

In modern chemical processes, identification of the process variable connectivity and their topology is vital for maintaining the operational safety. As a general information theoretic method, transfer entropy can analyze the causality between two variables based on estimation of conditional probability density functions. Transfer entropy estimation is typically a data driven method, however, the associated high computational complexity and poor accuracy are not acceptable in real applications. Using a nonlinear stochastic state-space model in conjunction with particle filters, a novel transfer entropy estimation method is proposed. The proposed approach requires less data, is fast and accurate.

MoD3 Room T2

Modeling of Biological Systems (Regular Session)

Chair: Guzman, Jose Luis	Univ. of Almeria
Co-Chair: Bar, Nadav S.	Norwegian Univ. of Science & Tech. (NTNU)

15:50-16:10 MoD3.1

From MFA to FBA: Legitimating Objective Function and Linear Constraints, pp. 460-465

Bogaerts, Philippe	Univ. Libre De Bruxelles
Richelle, Anne	Univ
Mhallem Gziri, Khadija	Univ. Libre De Bruxelles, 3BIO-BioControl

A careful analysis of the admissible metabolic flux intervals (determined from linear programs) obtained with detailed (input and output) or limited (only input) flux measurements is proposed in a case study made of a fed-batch culture of hybridoma cells. It is shown how a cost function in FBA and additional linear constraints on the fluxes can be legitimated and efficiently introduced so as to recover admissible flux intervals based on limited external measurements which are similar to the ones based on all the available measurements. A way to model overflow metabolism on both glucose and glutamine thanks to only two inequality constraints is proposed.

16:10-16:30 MoD3.2

Application of Dynamic Metabolic Flux Convex Analysis to CHO-DXB11 Cell Fed-Batch Cultures, pp. 466-471

Fernandes, Sofia	Univ. of Mons
Robitaille, Julien	Lab. in Applied Metabolic

	Engineering, Department of Chemi
Bastin, Georges	Univ. Catholique De Louvain
Jolicoeur, Mario	École Pol. De Montreal
Vande Wouwer, Alain	Univ. De Mons

In this work, a dynamic metabolic flux analysis based on convex analysis (DMFCA) is applied to CHO-DXB11 cell fed-batch cultures. This approach exploits all the available knowledge of the metabolic network and the time evolution of extracellular component concentrations, to determine bounded intervals for the fluxes continuously over time. Smoothing splines and mass balance differential equations are used to estimate the time evolution of the uptake and excretion rates from experimental data. Furthermore, the method is suitable for underdetermined systems, and does not require the definition of ad-hoc objective functions to be optimized. Moreover the metabolic network considered in this work allows an estimation of the carbon dioxide flux.

16:30-16:50 MoD3.3

New Iterative Approach (ISNCA) for Constrained Matrix Factorization Methods, pp. 472-477

Bar, Nadav S.	Norwegian Univ. of Science & Tech. (NTNU)
Jayavelu, Naresh D.	Univ. of Turku and Åbo Akademi Univ

Gene regulation networks are complex, often involve thousands of genes, regulators and the connections between them. To understand the complex interactions between these genes and regulators with time, large empirical data is used the so called time-series gene expression data. Many statistical tools are used to analyze this data but they often impose restrictions that reduce the size of the network and make the solution less feasible from a biological perspective. We developed the iterative subnetwork component analysis (ISNCA), a method that decomposes the empirical data of two or more overlapping subnetworks with joint components at one iteration, and updates the solution at the next iteration by subtracting the contribution of each of the subnetworks. This predict - update method managed to relax the restrictions and solve larger networks. We generalized the method in this paper to include both regulators and genes in the joint partition, and demonstrated its accuracy using a synthetic network with a known matrix decomposition. We also applied the ISNCA on large biological data taken from mice cells and obtained larger and more accurate solutions than achieved by previous methods.

16:50-17:10 MoD3.4

Event-Based Selective Control Strategy for Raceway Reactor: A Simulation Study, pp. 478-483

Pawlowski, Andrzej	UNED
Fernández Sedano, Ignacio	Univ. of Almeria
Guzman, Jose Luis	Univ. of Almeria
Berenguel, Manuel	Univ. of Almeria
Acién Fernández, Francisco Gabriel	Univ. of Almeria
Dormido, Sebastián	UNED

This work presents a simulation study of an event-based selective control strategy for a raceway reactor. The control system aims are to maintain simultaneously a pH and dissolved oxygen within specific limits. In the analyzed control scheme, the pH value is prioritized over the dissolved oxygen, since it has a critical influence on the process performance. Besides, the dissolved oxygen also influences the photosynthesis rate and should be kept within the limits. The control structure is evaluated through simulation, where a nonlinear model for microalgae culture in the raceway photobioreactor is used. Analysis of different configurations allows to determine the most adequate control system setup to achieve the desired goals. The obtained results show that combination of an event-based approach with selective control allows to increase the overall productivity as well as to address effective CO$_2$ utilization and aeration system energy minimization.

MoD4 Room T4

Inferential Sensing, State Estimation and Sensor Development I (Regular Session)

Chair: Porru, Marcella	Eindhoven Univ. of Tech
Co-Chair: Kano, Manabu	Kyoto Univ

15:50-16:10 MoD4.1

Development of a Moving Window Maximum Likelihood Parameter Estimator and Its Application on Ideal Reactive Distillation System, pp. 484-489

Valluru, Jayaram	Indian Inst. of Tech. Bombay
Purohit, Jalesh	Chemical Engineering Department, Dharmsinh Desai Univ. Nad
Patwardhan, Sachin C.	Indian Inst. of Tech. Bombay
Biegler, Lorenz T.	Carnegie Mellon Univ

Estimation of slowly varying model parameters/unmeasured disturbances is of paramount importance in process monitoring, fault diagnosis, model based advanced control and online optimization. The conventional approach to estimate drifting parameters is to model them as a random walk process and estimate them simultaneously with the states. However, this may lead to a poorly conditioned problem, where the tuning of the random walk model becomes a non-trivial exercise. Recently, Huang et al. (2010) has proposed a novel moving window weighted least squares parameter estimation approach, which is capable of simultaneous estimation of states and slowly drifting parameters/unmeasured disturbances. The slowly drifting parameters are assumed to remain constant in a time window in the immediate past and are estimated by solving a constrained minimization problem formulated over the window. In this work, the moving window parameter estimator of Huang et al. (2010) is recast as a moving window maximum likelihood (ML) estimator. It is assumed that the innovation sequence generated by the DAE-EKF is a Gaussian white noise process and further used to construct a likelihood function that treats the drifting model parameters as unknowns. This leads to a well conditioned problem where the only tuning parameter is the length of the moving window, which is much easier to select than selecting the covariance of the random walk model. Efficacy of the proposed ML formulation has been demonstrated by conducting simulation studies on an ideal reactive distillation system. Analysis of the simulation results reveals that the proposed moving window ML estimator is capable of tracking the drifting unmeasured parameter fairly accurately using only the tray temperature measurements.

16:10-16:30 MoD4.2

Simulation Study of the Particle Filter and the EKF for State Estimation of a Large-Scale DAE-System with Multi-Rate Sampling, pp. 490-495

Haßkerl, Daniel	TU Dortmund
Arshad, Momin	TU Dortmund
Hashemi, Reza	TU Dortmund
Subramanian, Sankaranarayanan	TU Dortmund
Engell, Sebastian	TU Dortmund

In the present contribution we study the application of the Particle Filter (PF) and of the Extended Kalman Filter (EKF) incorporating measurements at different sampling rates for the state estimation of a large-scale model. We investigate a model of an intensified chemical process (a reactive distillation (RD) process) that is represented by a nonlinear DAE-system and has more than 100 states. The EKF and PF schemes are studied for two different cases. The performance of each of the estimation method is compared first for the case where the estimator uses a model which is identical to the process Secondly, the model used by the estimator is considered to be parametrically different from the model used to simulate the process. The effect of model-plant mismatch on the mean squared estimation error is studied for both state estimation methods. The goal is to give arguments for the selection of either of the methods to be used at the real process unit fulfilling the requirements of accurate estimation and real-time capability.

16:30-16:50 MoD4.3

Systematic Observability and Detectability Analysis of Industrial Batch Crystallizers, pp. 496-501

Porru, Marcella	Eindhoven Univ. of Tech
Ozkan, Leyla	Eindhoven Univ. of Tech

Motivated by the lack of hardware analysers for particle size distribution (PSD) and solute concentration measurements in industrial crystallizers, this work investigates the feasibility of designing alternative monitoring tools based on state observers. The observability and detectability properties of the discretized population balance equation accounting for crystal growth, attrition and agglomeration coupled with energy and solute mass balances are studied. A systematic methodology for sensor selection based on nonlinear observability and detectability principles is proposed and applied. Results are corroborated by a machine learning technique (the self-organizing map), leading to the fact that the solute concentration is distinguishable with temperature measurements, while the PSD is not. The results represent the starting point for future detector design where temperature measurements are used to infer composition, while the estimation of the PSD is done in "open loop" fashion.

16:50-17:10 MoD4.4

Sparse Sample Regression Based Just-In-Time Modeling (SSR-JIT): Beyond Locally Weighted Approach, pp. 502-507

Uchimaru, Taku	Kyoto Univ
Kano, Manabu	Kyoto Univ

In the present work, a new method for just-in-time (JIT) modeling is proposed. To develop virtual sensors or soft-sensors that can cope with changes in process characteristics as well as nonlinearity, JIT modeling such as locally weighted regression (LWR) and locally weighted partial least squares (LW-PLS) has been investigated and successfully used in various industries. The conventional JIT modeling methods predict output variables by constructing a local model by using past samples located in the neighborhood around the new target sample (query) every time when the output prediction is required; the modeling samples are selected or weighted according to the similarity between the samples and the query. The similarity is usually determined on the basis of the distance from the query. However, the use of distance does not assure the high prediction accuracy. To overcome this limitation of the conventional JIT methods, the proposed method selects past samples that are useful for constructing an accurate local model by using elastic net, which builds a sparse regression model to estimate the query, and uses the derived regression coefficients to evaluate the similarity for conducting LW-PLS. This sparse sample regression based just-in-time modeling (SSR-JIT) has a potential for surpassing the conventional distance-based JIT modeling. In fact, it was demonstrated that SSR-JIT outperformed LW-PLS in the prediction accuracy through two case studies with real industrial data.

17:10-17:30 MoD4.5

On-Line Full Probability Distribution Identification of ARX Model Parameters Based on Bayesian Approach, pp. 508-513

Valadkhani, Amir Hosein	APAC Res. Group, Industrial Control Center of Excellence, Fa
Khormali, Aminollah	K. N. Toosi Univ. of Tech
Aliyari Shoorehdeli, Mahdi	K. N. Toosi Univ. of Tech
Khaloozadeh, Hamid	K. N. Toosi Univ. of Tech
Fatehi, Alireza	K. N. Toosi Univ. of Tech

In this contribution, full probability distribution of parameters of ARX model is obtained for on-line problems by means of Bayesian approach and Markov chain Monte Carlo method (MCMC), which provides the ability to be applied on time-varying ARX models as well. Full probability distribution of parameters represent whole available knowledge of parameters. So, decision makers can follow any policies to make decision about point estimation, like dynamic point estimation. Moreover, the Bayesian approach has great potential in combining sources of knowledge much more easier. To decrease the computational efforts, full probability of model parameters are updated based on size-varying partitions. Furthermore, incorporating the posterior probability of previous partition into the jump probability of current partition, in MCMC method, improves the performance of the proposed algorithm from the computation and convergence rate point of view. Simulation results demonstrate the effectiveness and validity of the proposed algorithm.

Technical Program for Tuesday June 7, 2016

TuPL Room T1

Plenary II Krister Forsman: "Implementation of Advanced Control in the Process Industry without the Use of MPC" (Plenary Session)

Chair: Imsland, Lars — Norwegian Univ. of Science & Tech. (NTNU)

Co-Chair: Skogestad, Sigurd — Norwegian Univ. of Science & Tech. (NTNU)

08:15-09:10 TuPL.1

Implementation of Advanced Control in the Process Industry without the Use of MPC, pp. 514-519

Forsman, Krister — Perstorp AB

In the process industry, such as chemical, pulp and paper or petrochemical industry there are plenty of processes that require multivariable control. Classical control structures that handle this, for example cascade control, feedforward, ratio control, and parallel control have been used at least since the 1930s. Today, much focus in academia is on model predictive control (MPC). In this paper we discuss the comparative advantages and disadvantages of classical control structures and MPC.

TuK1N1 Room T2

Keynote I (Semi-Plenary Session)

Chair: Zavala, Victor M. — Univ. of Wisconsin-Madison

Co-Chair: Budman, Hector M. — Univ. of Waterloo

09:15-09:45 TuK1N1.1

Parsimonious Cooperative Distributed MPC for Tracking Piece-Wise Constant Setpoints, pp. 520-525

Razzanelli, Matteo — Univ. of Pisa. Department of Information Engineering

Pannocchia, Gabriele — Univ. of Pisa

Distributed Model Predictive Control refers to a class of predictive control architectures in which a number of local controllers manipulate a subset of inputs to regulate a subset of outputs composing the overall system. These controllers may cooperate to find an optimal control sequence that minimizes a global cost function, as in the case of Cooperative Distributed Model Predictive Control (CD-MPC). In this paper two linear CD-MPC algorithms for tracking are proposed. The aim of these controllers is to drive the outputs of the overall system to any admissible piece-wise constant set-point, satisfying input and state constraints. However, in the available literature this result is achieved by using a set of centralized variables that keep track of the global state of the system. In contrast, we develop novel CD-MPC approaches for tracking that rely on "as local as possible" information instead of the plant-wide information flow. These new control strategies reduce the required communication overhead, local computational demands, and are more scalable than CD-MPC algorithms available in the literature. We illustrate the main characteristics and benefits of the proposed approaches by means of a multiple evaporator process example.

TuK1N2 Room T1

Keynote III (Semi-Plenary Session)

Chair: Skogestad, Sigurd — Norwegian Univ. of Science & Tech. (NTNU)

Co-Chair: Imsland, Lars — Norwegian Univ. of Science & Tech. (NTNU)

09:15-09:45 TuK1N2.1

Control Loop Performance Monitoring – ABB's Experience Over Two Decades, pp. 526-532

Starr, Kevin — ABB Inc

Bauer, Margret — Univ. of the Witwatersrand

Petersen, Heiko — ABB Automation GmbH

When process control systems do not perform as they should, plant personnel will not obtain positive results and may even give up using some control loops entirely. To increase productivity and efficiency it must be ensured that the control system is used effectively. The best way to do this is to turn the automatic control on and to tune it correctly. This paper describes the expertise in control loop performance monitoring gathered by ABB's control experts. With more automated production processes and fewer experts, control loop performance monitoring (LPM) needs to be able to evaluate one hundred loops at a time instead of loop-by-loop analysis. This cannot be done with training or manual tools. In this paper, ABB's perspective on loop performance monitoring as well as several novel features is described. Finally, further research directions are highlighted.

TuK2N1 Room T1

Keynote II (Semi-Plenary Session)

Co-Chair: Budman, Hector M. — Univ. of Waterloo

09:45-10:15 TuK2N1.1

Vinyl Acetate Monomer (VAM) Plant Model : A New Benchmark Problem for Control and Operation Study, pp. 533-538

Machida, Yuta — Omega Simulation Co., Ltd

Ootakara, Shigeki — Mitsui Chemical Inc

Seki, Hiroya — Tokyo Inst. of Tech

Hashimoto, Yoshihiro — Nagoya Inst. of Tech

Kano, Manabu — Kyoto Univ

Miyake, Yasuhiro — Ube Industries, Ltd

Anzai, Naoto — Zeon Corp

Sawai, Masayoshi — Zeon Corp

Katsuno, Takashi — Yokogawa Electric Corp

Omata, Toshiaki — Yokogawa Electric Corp

A rigorous dynamic plant model of a vinyl acetate monomer (VAM) production was developed. This plant model enables the users to experience realistic plant operation, since it reflects the real plant characteristics and practical problems on the basis of experienced practitioners' opinions. More importantly, the plant model provides a new benchmark problem; the users can investigate start-up/shut-down operation, plant-wide process control, fault detection and diagnosis, and others. Multiple scenarios prepared in the developed model cannot be simulated in conventional benchmark problems. The plant model can be used also for chemical engineering education. This advantageous plant model is released from Omega Simulation Co., Ltd. with a free limited license of Visual Modeler, which is a commercial dynamic simulator and can be linked with MATLAB®. This article aims to introduce the VAM plant model, the steady-state balance, various disturbances and malfunctions, and operation scenarios.

TuK2N2 Room T2

Keynote IV (Semi-Plenary Session)

Chair: Mulas, Michela — Aalto Univ.

Co-Chair: Villez, Kris — Eawag

Organizer: Budman, Hector M. — Univ. of Waterloo

09:45-10:15 TuK2N2.1

Operation of an Innovative WWTP with Environmental Objectives. a Model-Based Analysis, pp. 539-543

Mauricio-Iglesias, Miguel — Univ. De Santiago De Compostela

Garrido, Juan Manuel — Univ. De Santiago De Compostela

Lema, Juan Manuel — Univ. De Santiago De

Compostela

Operation of wastewater treatment plants can be subjected to economic, energetic and/or environmental objectives, besides the compliance with effluent limits. As trade-offs between different objectives are frequently unavoidable, model based analysis can assist in decision making and give further insight on the effect of the operating conditions. Furthermore, as new wastewater treatment technologies have appeared in the latest years, model-based analysis is needed to ascertain what the advantages of the new technologies are. We demonstrate here how to assess and operate an innovative WWTP according to different objectives with case-study based on a real innovative pilot plant. The plant features the use of denitrifying anaerobic methane oxidation (DAMO) bacteria to deplete methane from digestate. Furthermore, given the slow growth rate of the system and the tendency to create complex syntrophic environments, the use of a model becomes a keystone to operate these reactors.

TuA1 Room T1

Industrial Control Applications (Regular Session)

Chair: Alsop, Nicholas — Borealis AB

Co-Chair: Li, Qin — Statoil ASA

10:30-10:50 TuA1.1

Modelling and Robustness Analysis of Model Predictive Control of Electrical Submersible Pump Lifted Heavy Oil Wells, pp. 544-549

Krishnamoorthy, Dinesh — Statoil ASA

Bergheim, Elvira Marie — Statoil ASA

Pavlov, Alexey — Statoil ASA

Fredriksen, Morten — Statoil ASA

Fjalestad, Kjetil — Statoil ASA

In this paper we consider the problem of automatic control of oil production wells equipped with Electric Submersible Pumps (ESP). To facilitate robustness analysis of automatic control algorithms for such systems, a high fidelity simulator of ESP lifted well producing heavy viscous crude oil, has been developed. Model Predictive Control strategy proposed by the authors in an earlier publication has been tested on this simulator with the main focus on controller performance and robustness. The results demonstrated sufficient robustness of the controller with respect to system nonlinearities, variations in operating conditions, disturbances and measurement noise.

10:50-11:10 TuA1.2

Implementing Mid Ranging in a DCS Environment, pp. 550-555

Alsop, Nicholas — Borealis AB

Mid ranging is an algorithm for controlling one control variable, such as flow or pressure, with two manipulated variables. Although mid ranging is a very well established technique there are a number of practical issues which must be addressed when implementing mid ranging in the DCS. These issues include handicapped operation, bump less transfer and proper handling of saturation conditions. In this article, an algorithm for mid ranging is presented which exploits the inbuilt functionality of the control blocks in a modern DCS. A specific feature of the algorithm is the ability to maintain control even when one of the manipulated variables is out of service. Finally the article also demonstrates how the algorithm is extended to handle three manipulated variables.

11:10-11:30 TuA1.3

Robustness Analysis and Tuning for Pressure Control in Managed Pressure Drilling, pp. 556-561

Li, Qin — Statoil ASA

Kamel, Mina — ETH Zurich

In this paper, we present a general framework for robustness analysis for pressure control in managed pressure drilling (MPD). In particular, we apply the analysis to the pressure controller proposed in the work Godhavn et al. (2011), based on which we also give an approach to search for controller tuning parameters with the goal of maximizing the robustness of system stability and control performance to various sorts of uncertainties, disturbances and noise. The resulting tuning table can be used for online computation of the controller parameters. The method proves effective in a simulation study.

11:30-11:50 TuA1.4

Nonlinear MPC for Grade Transitions in an Industrial LDPE Tubular Reactor, pp. 562-567

Skalen, Staffan — Borealis AB

Josefsson, Fredrik — Borealis AB

Ihrström, Joakim — Borealis AB

A detailed physical model has been developed for an industrial 350 kt/year low-density polyethylene tubular reactor and implemented in a proprietary non-linear Model Predictive Control framework to control product quality during grade transitions. The controller is now at the end of the commissioning phase and is regularly used during transitions. Improved transition control reduces the amount of off-spec product, which improves the profit of the plant as well as the consistency during transitions compared to the manual transition control scheme used previously.

11:50-12:10 TuA1.5

Economic Model Predictive Control (EMPC) of an Industrial Diesel Hydroprocessing Plant, pp. 568-573

Arkun, Yaman — Koc Univ

Aydin, Erdal — Koc Univ

Is, Gamze — TUPRAS

Diesel hydroprocessing is a refinery process by which the sulfur impurities are removed by hydrodesulfurization to satisfy the environmental sulfur constraint levels and the main product diesel is obtained by hydrocracking. The industrial Diesel Hydroprocessing Plant subject to this study consists of two hydrodesulfurization reactors and one hydrocracking reactor in series. The feed to the plant is a blend of four different raw material streams which are heavy diesel (HD), light diesel (LD), light vacuum gas oil (LVGO) and imported diesel from another refinery. A two-layer, hierarchical Economic Model Predictive Control (EMPC) structure is proposed to maximize the profit of the industrial diesel hydroprocessing plant. The plant-wide profit is maximized by computing the optimal set points by the upper economic model predictive control layer while these set points are tracked by the regulatory model predictive controllers in the lower level. Set point tracking and disturbance rejection performances of the proposed EMPC structure are tested through closed-loop simulations and the results are presented in this work.

TuA2 Room T3

Model Based Control II (Regular Session)

Chair: Dochain, Denis — Univ. Catholique De Louvain

Co-Chair: Alvarez, Jesus — Univ. Autonoma Metropolitana

10:30-10:50 TuA2.1

Asymptotic Tracking of Periodic Operation Based on Control Contraction Metrics, pp. 574-578

Wang, Ruigang — Univ. of New South Wales

Bao, Jie — Univ. of New South Wales

Periodic operations can be beneficial to chemical and biological systems, leading to better efficiency and plant economy compared to steady state operation. In this paper, the tracking control of desired periodic operation based on control contraction metrics is considered. A relaxation method is proposed to convert the nonconvex control synthesis problem into a convex sum-of-squares programming. Finally, an application to a Lotka-Volterra system of sustained oscillating chemical reactions is presented for illustration. The main advantages of this approach include: (1) the feedback information is geodesics, which is a general deviation considering local nonlinearity; (2) the differential state feedback control law is reference trajectory independent; (3)

the control design can be carried out via numerical optimization.

10:50-11:10 TuA2.2

On the Equivalence of Storage Functions in Controlled Thermodynamic Systems, pp. 579-584

Hoang, Ngoc Ha	Univ. of Tech. (VNU-HCM) and Univ. Cath. De Louvain (Belgiu
Dochain, Denis	Univ. Catholique De Louvain

Motivated by thermodynamic concepts strongly related to the second law of thermodynamics, this paper deals with the mathematical foundations of thermodynamics to reconstruct some storage functions usable both for the stability analysis and control of homogeneous chemical processes through the case study of non isothermal continuous stirred tank reactors (CSTRs). Besides, the equivalence of the storage functions in the thermodynamics framework is also shown.

11:10-11:30 TuA2.3

Geometric-Dissipative Control of Exothermic Continuous Reactors, pp. 585-590

Alvarez, Jesus	Univ. Autonoma Metropolitana
Franco, Hugo	Univ. Nacional Autónoma De México

The problem of robustly stabilizing through output-feedback control an open-loop unstable exothermic continuous reactor with temperature measurement is addressed. The combination of advanced geometric control and classical mechanics methods yields: (i) solvability of the detailed model-based nonlinear output-feedback problem in terms of passivity, observability and dissipativity, (ii) open-loop energy and closed-loop Lyapunov functions in analytic form, and (iii) the tradeoff between response speed, robustness, and control effort. On the basis of simplified model tailored according to the passivity-observability-dissipativity structure, the advanced geometric observer-based nonlinear controller is realized with an industrial-like PID controller. The methodology is illustrated with numerical simulations.

11:30-11:50 TuA2.4

Low-Order Feedback-Feedforward Controller for Dead-Time Processes with Measurable Disturbances, pp. 591-596

Rodríguez, Carlos	UNED
Normey-Rico, Julio Elias	Univ. Federal De Santa Catarina
Guzman, Jose Luis	Univ. of Almeria
Berenguel, Manuel	Univ. of Almeria
Dormido, Sebastián	UNED

This paper presents simple tuning rules for low-order feedback and feedforward controllers based on an approximation of the filtered Smith predictor with closed-loop feedforward compensation. An analytical development is introduced to control stable first-order plus dead time processes affected by measurable disturbances that cannot be completely removed from the process output due to dead-time effects. Simulation results for the pH control of a tubular photobioreactor and the steam pressure control of an industrial boiler are given to show the effectiveness of the proposed method.

11:50-12:10 TuA2.5

Distributed Nonlinear Model Predictive Control by Sequential Linearization and Accelerated Gradient Method, pp. 597-602

Grancharova, Alexandra	Univ. of Chemical Tech. and Metallurgy
Johansen, Tor Arne	Norwegian Univ. of Science & Tech. (NTNU)
Petrova, Valeria	Univ. of Chemical Tech. and Metallurgy

A suboptimal approach to distributed NMPC for nonlinear interconnected systems subject to constraints is proposed. The objective is to develop a computationally efficient approach. The suggested method is based on a sequential linearization of the nonlinear system dynamics and finding a suboptimal solution of the resulting Quadratic Programming problem by using distributed iterations of the dual accelerated gradient method. The benefits of the approach are reduced complexity of the on-line computations, and simple software implementation, which makes it appropriate for embedded distributed convex NMPC. The proposed method is illustrated with simulations on the model of a quadruple-tank system.

TuA3 Room T2

Bioreactor Process Monitoring and Modeling (Regular Session)

Chair: Reichl, Udo	Max Planck Inst. for Dynamics of Complex Tech
Co-Chair: Gerogiorgis, Dimitrios I.	Univ. of Edinburgh

10:30-10:50 TuA3.1

Segmentation and Quantitative Analysis of Normal and Apoptotic Cells from Fluorescence Microscopy Images, pp. 603-608

Du, Yuncheng	Univ. of Waterloo
Budman, Hector M.	Univ. of Waterloo
Duever, Thomas	Ryerson Univ

Accurate and fast quantitative analysis of living cells from fluorescence microscopy images is useful for evaluations of experimental outcomes and cells culture protocols. An algorithm is developed in this work to automatically segment and discern apoptotic cells from normal cells. A coarse segmentation algorithm is proposed as a pre-filtering step that combines a range filter with a marching square method. This step provides approximate coordinates of cells' positions in a two-dimensional matrix used to store cells' image. With this information, the active contours without edges method is applied to identify cells' boundaries and subsequently it is possible to extract the mean value of intensity within the cellular regions, the variance of pixels' intensities in the vicinity of cells' boundaries and the lengths of the boundaries. These morphological features are then employed as inputs to a support vector machine (SVM) classifier that is trained to distinguish apoptotic from normal viable states of cells. The algorithm is shown to be efficient in terms of computational time, quantitative analysis and differentiation accuracy, as compared to the use of the active contours method without the proposed coarse segmentation step.

10:50-11:10 TuA3.2

On-Line Monitoring of Substrates and Biomass Using Near-Infrared Spectroscopy and Model-Based State Estimation for Enzyme Production by S. Cerevisiae, pp. 609-614

Krämer, Dominik	Tech. Univ. Berlin
King, Rudibert	Tech. Univ. Berlin

In the early process development, feeding trajectories and cultivation conditions are altered in order to maximise the desired product. This is in contrast to industrial cultivations, where variations are to be eliminated. In order to fully understand and safely run a new process, real-time information are beneficial. Near-infrared spectrometer that are coupled to a fermenter offer the possibility to gather information on-line. The NIR data can be transformed via partial least squares modeling to estimate substrate and biomass concentrations. At low concentrations and under changed cultivation conditions during process development, however, the estimates may differ from reality. This uncertainty may be reduced by integrating biological and physico-chemical knowledge in the on-line estimation. In this contribution, we present a hybrid approach of near-infrared (NIR) spectroscopy and nonlinear model-based state estimation to enable an improved quality in the on-line estimation of substrates and biomass in a yeast cultivation. As only three cultivations are needed for calibration, on-line state estimation is available in the early stage of development for this process. This approach is compared to the use of both methods separately for estimation of biomass, ammonium, glucose, phosphate and ethanol in cultivations of *S.*

cerevisiae.

11:10-11:30 TuA3.3

Dynamic Simulation and Visualisation of Fermentation: Effect of Process Conditions on Beer Quality, pp. 615-620

Rodman, Alistair R. — Univ. of Edinburgh
Gerogiorgis, Dimitrios I. — Univ. of Edinburgh

Fermentation is the central, most important unit operation in alcoholic beverage manufacturing and has already been studied by means of first-principles dynamic models, which explicitly consider the temperature effects and employ parameterisations obtained using industrial beer brewing campaign data. Nevertheless, the precise effect of initial conditions on beer quality and flavour has not been documented. Multi-objective optimisation encompasses ethyl alcohol maximization and batch duration minimisation, but must also quantitatively monitor all the critical flavour components (Rodman & Gerogiorgis, 2016). Dynamic simulation and visualisation of the key (ethyl alcohol, ethyl acetate, diacetyls) concentrations is pursued for varying initial condition (sugar concentration, pitching rate, active yeast fraction) parameters, and hundreds of thousands of possible temperature manipulation profiles over the entire brewing horizon. Feed sugar content is confirmed to govern attainable alcohol concentration, but our notable finding is that pitching rate is a very efficient manipulation, in contrast to the weak effect of initial active yeast fraction.

11:30-11:50 TuA3.4

Efficient Generation of Models of Fed-Batch Fermentations for Process Design and Control, pp. 621-626

Hebing, Lukas — TU Dortmund
Neymann, Tobias Claus — TU Dortmund
Thüte, Tobias — Bayer HeathCare AG
Jockwer, Alexander — Bayer HeathCare AG
Engell, Sebastian — TU Dortmund

The paper presents a fast and efficient approach to the generation of process models for fed-batch fermentation processes. Elementary Modes (EM) with kinetic terms are used as macro-reactions in the model. A method based upon dynamic metabolic flux analysis (DMFA) is used to find an optimal selection of EM based on concentration measurements instead of reaction rates that must be calculated from the measurements. A multi-objective genetic algorithm is used to investigate the tradeoff between the number of EM and the difference of the estimated concentration profiles from the available measurements. Thus the number of macro-reactions for the model is kept small but the measured data are described sufficiently well by the selected EM. The influence of the process conditions on each macro-reaction rate are identified by a statistical analysis and kinetic expressions are fitted to the estimated evolutions by solving multiple simple optimization problems instead of a multi-dimensional large-scale nonlinear parameter optimization problem. The resulting process model provides a good fit of the measurement data. Provided that the data is generated by a systematic approach, e.g., using a design of experiments strategy, the modelling procedure provides models of adequate complexity that are valid within the so-called design space of the process.

11:50-12:10 TuA3.5

Modelling the Production of Soluble Hydrogenase in Ralstonia Eutropha by On-Line Optimal Experimental Design, pp. 627-632

Neddermeyer, Flavia — Tech. Univ. Berlin
Marhold, Volker — Tech. Univ. Berlin
Menzel, Christoph — Tech. Univ. Berlin
Krämer, Dominik — Tech. Univ. Berlin
King, Rudibert — Tech. Univ. Berlin

This paper presents a case study on integrating a new model branch describing the production of the enzyme soluble hydrogenase (SH) into an already existing model by means of on-line experimental design (OED). These investigations were done on the autotrophic cultivation system and process model of Ralstonia eutropha, i. e., a cultivation where aeration by air is replaced by a gas consisting of H2/O2/CO2. Prior to the experiment, three different structures of the new model extension are postulated and coarsly identified. Off-line OED with the best model yields initial feeding trajectories. During the experiment, a repetitive model refinement is performed. This consists of identifying the parameters of the new model extension for all three models, selecting the best model and recalculating optimal feeding trajectories. It is shown that on-line OED in the early modelling stage followed by a manual modelling step results in an acceptable description of SH production.

TuA4 Room T4

Application of PSE Tools to CO2 Capture, Utilization and Storage (Invited Session)

Chair: Lee, Jay H. — KAIST
Co-Chair: Ricardez-Sandoval, Luis Alberto — Univ. of Waterloo
Organizer: Lee, Jay H. — KAIST
Organizer: Ricardez-Sandoval, Luis Alberto — Univ. of Waterloo

10:30-10:50 TuA4.1

Advanced Modeling and Control of a Solid Sorbent-Based CO2 Capture Process (I), pp. 633-638

Omell, Benjamin — West Virginia Univ
Ma, Jinliang — National Energy Tech. Lab
Mahapatra, Priyadarshi — National Energy Tech. Lab
Yu, Mingzhao — Carnegie Mellon Univ
Lee, Andrew — National Energy Tech. Lab
Bhattacharyya, Debangsu — West Virginia Univ
Zitney, Stephen E. — National Energy Tech. Lab
Biegler, Lorenz T. — Carnegie Mellon Univ
Miller, David — National Energy Tech. Lab

Solid sorbent-based CO2 capture provides a novel alternative to traditional solvent-based processes due to lower energy consumption for regeneration. Optimal operation of such a process requires an advanced control framework for efficient disturbance rejection and setpoint tracking. This work focuses on the development of computationally fast and accurate dynamic reduced models (D-RMs) and the application of these models to nonlinear model predictive control (NMPC) algorithms. Two different types of D-RMs are developed: the first type is a data-driven model where step test data are utilized to generate the D-RM through the Decoupled A-B Net (DABNet) model, and the second type of D-RM is created by temporally and spatially reducing the original model to improve its computational efficiency while still retaining the physics of the original model. Disturbance rejection and setpoint tracking characteristics of the NMPC and its computational performance is studied for both types of D-RMs. In addition, performance of both NMPC formulations are compared with linear model predictive control (LMPC) formulations.

10:50-11:10 TuA4.2

Dynamic Data Reconciliation and Model Validation of a MEA-Based CO2 Capture System Using Pilot Plant Data (I), pp. 639-644

Chinen, Anderson Soares — West Virginia Univ
Morgan, Joshua — West Virginia Univ
Omell, Benjamin — West Virginia Univ
Bhattacharyya, Debangsu — West Virginia Univ
Miller, David — National Energy Tech. Lab

This work focuses on development of a “gold standard” process model for a MEA-based post-combustion CO2 capture process. The steady-state model includes a comprehensive thermodynamic framework in conjunction with the chemistry model. All thermodynamic and transport properties models are regressed using extensive data available in the literature. An integrated mass transfer model is developed and validated using experimental data. The steady-state model is validated using data collected from U.S. DOE's National Carbon Capture Center in Wilsonville, Alabama. In addition to the steady-state runs, dynamic test runs were conducted at NCCC by introducing carefully-designed step changes and recording the transients of all key variables. Due to measurement noise and missing measurements for a number of key variables, a dynamic data reconciliation problem was solved to ensure material and energy balance of the collected data. Both the steady-state and dynamic models were validated against plant data for a wide range of operating conditions.

11:10-11:30 TuA4.3

Dynamic Simulation and Analysis of a Pilot-Scale CO2 Post-Combustion Capture Unit Using Piperazine and MEA (I), pp. 645-650

Gaspar, Jozsef	Tech. Univ. of Denmark
Ricardez-Sandoval, Luis Alberto	Univ. of Waterloo
Jorgensen, John Bagterp	Tech. Univ. of Denmark
Fosbøl, Philip Loldrup	Tech. Univ. of Denmark

Post-combustion capture is a promising technology for developing CO2 neutral power plants. However, to make it economically and technically feasible, capture plants must follow the fast and large load changes of the power plants without decreasing the overall performance of the plant. Dynamic modeling and simulation is therefore needed to evaluate the performance of this plant under critical operation. In this work, we evaluate the transient response of an absorber and a desorber for step changes of key process parameters, e.g. flue gas flow and composition, lean and rich CO2 loading, etc. We show the results for the baseline 30 wt% MEA and the low energy piperazine (PZ) solutions. This analysis reveals that the absorber reaches steady-state faster using MEA compared to PZ. This is related to the shift of the mass transfer zone due to changes in temperature. The transient operation in the regeneration unit is somewhat similar while using both solvents: an initial fast decrease of the lean loading is followed by a slow transient period as the system approaches steady-state conditions. We show the presence of inverse response in the stripper column when the rich loading decreases or the feed's temperature reduces using PZ solvent. Thus, we demonstrate that the dynamics of the MEA system cannot be extrapolated to other solvents.

11:30-11:50 TuA4.4

New Performance Indicators for Evaluation of Adsorbents Developed for CO2 Capture with PSA Processes (I), pp. 651-656

Ga, Seongbin	KAIST
Jang, Hong	KAIST
Lee, Jay H.	KAIST

Pressure swing adsorption (PSA) process is one of the leading candidates for CO2 capture in the chemical industry. This leads to the development of various adsorbents such as modified zeolite materials and metal-organic frameworks (MOFs). The performance of the developed adsorbents is evaluated through the lab-scale methods based on the performance indices: working capacity and selectivity. However, the existing performance indices are not directly related to the practical performance of the adsorbents in a PSA process. In this work, we define new performance indices: efficiency and purity. Both are defined on the basis of an ideal PSA process, which means the best performance of a PSA process with target adsorbents. For the simple calculation and quick evaluation, the performance indices are derived to analytical solutions in the explicit form. The evaluation of zeolite 13X, activated carbon and Cu-BTC is also presented to show the use the new performance indices, and the results are compared with rigorous simulation results.

11:50-12:10 TuA4.5

A Sequential Method for Determining Optimal Stripper Pressure and Terminal Pressure in CO2 Capture and Liquefaction Process Using MEA (I), pp. 657-662

Park, Taekyoon	Seoul National Univ
Bae, Jaehan	Seoul National Univ
Lee, Chang Jun	Pukyong National Univ
Lee, Jong Min	Seoul National Univ

The pressure of a distillation column for regenerating an absorbent is one of the key variables for minimizing the energy in a carbon capture and storage (CCS) chain. The steam drag point in power plant, the regeneration energy in capture process and the compression energy in the liquefaction process are highly dependent on the pressure of regeneration column . In this work, a new method for determining optimal value of stripper pressure is proposed based on the integrated simulation model and sequential optimization method. Total required energy has been represented as a function of the stripper pressure and the terminal pressure. The results show that the higher pressure is generally recommended to reduce the required energy, revealing that the value of the stripper pressure depends on the liquefaction process more than the power plant.

TuB1 Room T1

Process Planning and Scheduling (Regular Session)

Co-Chair: Jogwar, Sujit — Inst. of Chemical Tech

13:00-13:20 TuB1.1

Bi-Level Demand Response Game with Information Sharing among Consumers, pp. 663-668

Zhang, Zhaohui	Univ. of Southern California
Deng, Ruilong	Univ. of Alberta
yuan, tao	Univ. of Southern California
Qin, S. Joe	Univ. of Southern California

In this paper, we formulate the demand response problem in smart grid as a bi-level game: a consumer-level noncooperative game and a one-leader-one-follower Stackelberg game between the provider-level and the consumer-level. We prove the existence of a Nash Equilibrium for the noncooperative game and a Stackelberg Equilibrium for the Stackelberg game, focus on the case with information sharing among all consumers, and design distributed algorithms for the supply side and demand side as well as the information platform. Numerical results are provided to illustrate the performance of the proposed algorithms and the effectiveness of information sharing for improving each consumer's pay off.

13:20-13:40 TuB1.2

A Pattern-Based Method for Scheduling of Energy-Integrated Batch Process Networks, pp. 669-674

Mete, Shrikant	Inst. of Chemical Tech
Jogwar, Sujit	Inst. of Chemical Tech

This paper describes a pattern-based method for the generation of flexible-horizon production schedules for energy-integrated batch systems using a benchmark reactor-distillation system. The proposed methodology consists of structural decomposition of an already existing schedule for a fixed time horizon to identify repetitive patterns. It is found that such a schedule can be divided into three sections - initial, final and an intermediate section - of manipulable sizes. Based on such a decomposition, it is possible to generate an extended (or shorter) horizon schedule by increasing (or decreasing) the sizes of these sections. The proposed method allows for the generation of new schedules without solving mathematically rigorous mixed integer programming problems. The key advantage of the proposed method is the significant reduction in the time required for solving large scheduling problems, especially for online rescheduling applications. The effectiveness of the proposed methodology is illustrated through the same benchmark scheduling problem.

13:40-14:00 TuB1.3

Production Scheduling of an Air Separation Plant, pp. 675-680

Misra, Shamik	Indian Inst. of Tech. Bombay

Kapadi, Mangesh	Praxair
Gudi, Ravindra	Indian Inst. of Tech. Bombay
Srihari, R	Praxair India Private Limited

Cryogenic air separation plants consume a large amount of electricity to produce various gaseous and liquid products; they can reduce their operational cost by proper exploitation of energy contracts and intelligent utilization of liquid products. In this paper, we propose a State Task Network(STN) based model which replicates a representative air separation plant. This STN based representation owing to its significantly more granular modelling can reap higher benefits in terms of improved decision making than the approaches proposed in literature. Production Scheduling based on this model computes the optimal operating conditions for the plant under variable power pricing options and demand scenarios. The modelling framework is very rigorous and includes almost all the real world limitations and constraints in air separation plant operation. This unit wise scheduling approach provides more flexibility and also pave the way for integration of the scheduling layer with the lower layered (hierarchically) control system. The proposed framework has been evaluated on the representative air separation plant and the results demonstrate the benefits of optimal plant operation.

14:20-14:40 TuB1.5

Moving Horizon Scheduling of an Air Separation Unit under Fast-Changing Energy Prices, pp. 687-692

Pattison, Richard C.	Univ. of Texas at Austin
Touretzky, Cara R.	Univ. of Texas at Austin
Johansson, Ted	Univ. of Texas at Austin
Baldea, Michael	Univ. of Texas at Austin
Harjunkoski, Iiro	ABB AG, Corp. Res

Maximizing the benefits of time-of-use pricing for industrial electricity consumers requires varying production rates, such that energy use is shifted from peak price periods to off-peak times during the day. Assuming that excess capacity and product storage are available, production of energy intensive processes can be increased at off-peak times beyond nominal rates, and the stored product can be used at peak times when the production rate is lowered. Under these rapidly changing circumstances, scheduling calculations must take into consideration explicitly the dynamic model of the process, often rendering the scheduling problem intractable in practical amounts of time. To address this challenge, we introduce a class of scheduling-relevant low-order process models, which capture the closed-loop input-output behavior of a plant. We use these models to close the scheduling loop, whereby the scheduling problem is formulated over a moving horizon with feedback. We apply the theoretical concepts to an industrial-scale air separation unit model, demonstrating that variable production rate operation with product storage has the potential for significant operating cost savings while abiding by product quality and safety constraints.

14:20-14:40 TuB1.5

KPIs As the Interface between Scheduling and Control, pp. 681-686

Bauer, Margret	Univ. of the Witwatersrand
Harjunkoski, Iiro	ABB AG, Corp. Res
Schlake, Jan-Christoph	ABB Corp. Res. Center
Lucke, Matthieu	Lund Univ
Johnsson, Charlotta	Lund Univ

The integration of scheduling and control has been discussed in the past. While constructing an integrated plant model that may still seems out of reach, scheduling and control systems are increasingly more intertwined. We argue that they are in fact already integrated and give the example of two key performance indicators (KPIs) that are defined in a recent standard. The focus of this study is on KPIs that consider both planned times as well as actual times. To illustrate the integration, a schedule is computed for a batch production process. Resulting measurements from the distributed control system are analyzed for their actual production times with a proposed procedure that detects the start and end time of batches.

Production planning and scheduling (P&S) generates a strategy how to utilize the equipment and assets in a plant to produce a set of products, often with the goal of minimizing the total production time (make span) or production costs. The production is executed on a production facility, coordinated by a distributed control system (DCS), which contains a number of functionalities including management and optimization for maintaining the stability, safety and quality of production. From the overall process point of view it is important that these systems that on one the hand make decisions on their own can work in a collaborative manner.

In the past, efforts to integrate scheduling and control systematically have not been successfully implemented in real life. The main reason for this is that the focus has been either to mathematically combine two different philosophies into a single model – or broaden the scope towards an area with a different time scope and physical complexity. Here, we do not put the focus on regulatory control (e.g. PID control) or on mathematical modelling but on the co-existence of scheduling and control within an industrial IT-landscape.

We claim that in practice, scheduling and control are already integrated, as the information from one to another is passed – either manually of automatically. The big potential arise from concepts such as internet of things (IoT) that enable communication channels between connected entities.

TuB2 Room T4

Performance and Fault Monitoring II (Regular Session)

Chair: Palazoglu, Ahmet N.	Univ. of California at Davis
Co-Chair: El-Farra, Nael H.	Univ. of California, Davis

13:00-13:20 TuB2.1

Use of Sparse Principal Component Analysis (SPCA) for Fault Detection, pp. 693-698

Gajjar, Shriram	Univ. of California at Davis
Palazoglu, Ahmet N.	Univ. of California at Davis
Kulahci, Murat	Tech. Univ. of Denmark

Principal component analysis (PCA) has been widely used for data dimension reduction and process fault detection. However, interpreting the principal components and the outcomes of PCA-based monitoring techniques is a challenging task since each principal component is a linear combination of the original variables which can be numerous in most modern applications. To address this challenge, we first propose the use of sparse principal component analysis (SPCA) where the loadings of some variables in principal components are restricted to zero. This paper then describes a technique to determine the number of non-zero loadings in each principal component. Furthermore, we compare the performance of PCA and SPCA in fault detection. The validity and potential of SPCA are demonstrated through simulated data and a comparative study with the benchmark Tennessee Eastman process.

13:20-13:40 TuB2.2

Stability Evaluation Based Non-Steady Variable Identification for Online Fault Prognosis, pp. 699-704

Zhao, Chunhui	Zhejiang Univ
Wang, Wei	China Tobacco Zhejiang Industrial Co. Ltd
GAO, Furong	Hong Kong Univ. of Sci & Tech

In the present work, an online fault prognosis strategy is developed for proactive abnormality management. For online prognosis, the fault degradation process should be well revealed. To well capture the evolution process, the proposed approach includes three components, First, the stability factor is defined to identify those significant faulty variables that show degradation process. Second, the fault variations departing from normal status are extracted by performing a modified Fisher discriminant analysis (MFDA) on the selected variables in normal and fault data. These critical variations are deemed to be evolving with time and thus responsible to the future process failure. Third, the significant variations are captured to track the fault evolution process for fault prognosis by developing a vector auto-regression model to reveal how soon the process failure will happen. By the above modeling strategy, uninformative fault effects that do not present degradation are excluded so that the true fault degradation process can be focused on for online fault prognosis. The proposed method is verified by both numerical and experimental data.

13:40-14:00 TuB2.3

Fault Detection of Multimode Processes Using Concurrent Projection to Latent Structures, pp. 705-710

Zheng, Ying — Huazhong Univ. of Science and Tech

Qin, S. Joe — Univ. of Southern California

Chai, Tianyou — Northeastern Univ

Process monitoring based on Concurrent Projection to Latent Structures (CPLS) has been proposed recently as an efficient process monitoring tool to detect the input-relevant and output-relevant faults. In this paper, a novel multimode process monitoring approach is proposed to introduce external analysis into the CPLS monitoring framework. The process variables are divided into external variables, main variables and the output variables. The mode change is detected by monitoring the variation of the external variables through a mode-detection CPLS. The prediction of the main and quality variables by external variables is done by a PLS. After the influence of the external variables is removed from the main and quality variables, another process-monitoring CPLS is built to detect the main-variable-relevant faults and quality-variable-relevant faults. The proposed approach is illustrated with a simulation process.

14:00-14:20 TuB2.4

A Model-Based Framework for Fault Estimation and Accommodation Applied to Distributed Energy Resources, pp. 711-716

Allen, James — Univ. of California, Davis

El-Farra, Nael H. — Univ. of California, Davis

This paper presents the development and approach of a model-based fault identification and accommodation framework applied to sampled-data controlled distributed energy resources subject to control actuator faults. The main objective of the proposed approach is to handle faults that degrade stability as well as performance, while remaining robust to false alarms. The proposed method allows for dual fault detection and estimation, through the use of an embedded system model that minimizes the residual between the estimated and sampled states at each sampling period by adjusting a fault parameter in the embedded model over a past horizon. The resulting fault parameter estimate is then used by the control system to find an optimal fault accommodation strategy by minimizing a predefined performance metric whilst ensuring closed-loop stability. The developed fault accommodation framework is then applied to a simulated model of a solid oxide fuel cell subject to both stability and performance degrading faults in the control actuators. A discussion of some of the practical implementation issues associated with the developed framework is also included.

14:20-14:40 TuB2.5

A Data-Driven Fault Detection Method Based on Dissipative Trajectories, pp. 717-722

Lei, Qingyang — Univ. of New South Wales

Munir, Muhammad Tajammal — Univ. of Auckland

Bao, Jie — Univ. of New South Wales

Young, Brent — Univ. of Auckland

Fault detection is becoming increasingly important as the complexity of industrial process develops. In this paper, a data-driven fault detection method is proposed. The dissipativity theory is adopted to find the appropriate dissipativity properties for the process input output trajectory. The dissipativity properties can be viewed as an 'abstract energy property', and the dissipativity properties of input output trajectories represent process dynamic features. As faults occur, the dissipative trajectories will change thus allow fault detection to be performed based on these dissipativity properties. A training algorithm is developed to search for the related properties using input output data. A prior knowledge of the process can be incorporated into the algorithm to facilitate the training. The proposed fault detection method is illustrated on a case study of a mono-chlorobenzene plant simulated using VMGSim.

14:40-15:00 TuB2.6

Causal Analysis for Alarm Flood Reduction, pp. 723-728

Rodrigo Marco, Vicent — Lund Univ

Chioua, Moncef — ABB Corp. Res. Germany

Hagglund, Tore — Lund Univ

Hollender, Martin — ABB Corp. Res

The introduction of distributed control systems and the high level of interconnectivity of modern process plants has caused alarm flooding to become one of the main problems in alarm management of process plants. A reduction of alarm flood periods contributes to a decrease in plant incidents. In this work, a combination of alarm log, process data and connectivity analysis is used to isolate consequence alarms originating from the same process abnormality and to provide a causal alarm suggestion. The effectiveness of the method is illustrated on an industrial case study of an ethylene plant, a typical example of a large-scale industrial system.

TuB3 — Room T3

Plantwide Control and Distillation (Regular Session)

Chair: Huusom, Jakob Kjøbsted — Tech. Univ. of Denmark

Co-Chair: Kaistha, Nitin — Indian Inst. of Tech. Kanpur

13:00-13:20 TuB3.1

Comparison of Stabilizing Control Structures for Dividing Wall Columns, pp. 729-734

Qian, Xing — Tianjin Univ

Jia, Shengkun — School of Chemical Engineering and Tech. Tianjin Univ

Skogestad, Sigurd — Norwegian Univ. of Science & Tech. (NTNU)

Yuan, Xigang — Tianjin Univ

The focus of this paper is to investigate stabilizing control (single-loop PID control) of a dividing wall column (DWC) for separating ethanol, n-propanol and n-butanol at atmospheric pressure. Three control structures are studied: control structure with fixed split ratios (CS1), control structure with an active liquid split (CS2) and control structure with an active vapor split ratio (CS3). The dynamic performances of the three proposed control structures prove that the three control structures are able to handle feed disturbances inserted into DWC. The simple control structure with fixed split ratios (CS1) is more applicable in industry. Considering the vapor split ratio disturbance, CS2 and CS3 are better than CS1. If the feed composition of A rarely changes, CS3 is able to handle the other feed disturbances. This paper proves that the three-product DWC can be controlled with only three temperature controllers.

13:20-13:40 TuB3.2

Integrated Process Design and Control of Multi-Element Reactive Distillation Processes, pp. 735-740

Mansouri, Seyed Soheil — Tech. Univ. of Denmark

Sales Cruz, Mauricio — Univ. Autonoma Metropolitana-Cuajimalpa

Huusom, Jakob Kjøbsted — Tech. Univ. of Denmark

Gani, Rafiqul — CAPEC, Department of Chemical and Biochemical Engineering, Tech

In this work, integrated process design and control of reactive distillation processes involving multi-elements is presented. The reactive distillation column is designed using methods and tools

which are similar in concept to non-reactive distillation design methods, such as driving force approach. The methods employed in this work are based on equivalent element concept. This concept facilitates the representation of a multi-element reactive system as binary light and heavy key elements. First, the reactive distillation column is designed at the maximum driving force where through steady-state analysis it is shown that it has the least energy consumption and carbon footprint. Next, through analytical and dynamic analysis it is verified that the control structure, disturbance rejection and the controllability at the maximum driving force is the best compared to any other design alternative which does not operate at the maximum driving force.

13:40-14:00	TuB3.3

Control System Design for Furnaces with Multiple Parallel Passes, pp. 741-746

Ojasvi, Ojasvi	Indian Inst. of Tech. Kanpur
Singh, Aryan	Indian Inst. of Tech. Kanpur
Kaistha, Nitin	Indian Inst. of Tech. Kanpur

Systematic control system design for process furnaces with multiple parallel tube passes is addressed. The control objectives are to regulate furnace outlet temperature while holding the temperature rise across the individual tubes to be the same (tube pass heat load balancing). With respect furnace throughput (Ftot), two operating scenarios are considered; 1. Ftot is held constant and (ii) short term transient variability in Ftot is acceptable. Alternative systems, CS1-CS3, are synthesized and quantitatively evaluated for their closed loop dynamic performance to expected load/servo changes. The Scenario 1 heat load balancing problem is shown to exhibit strong multivariable dynamic interaction and the control benefit of dynamic matrix control is quantified. Based on the results, recommendations are made on the suitability of the alternative control systems in industrial settings.

Keywords: Control System Design, Process Equipment, Furnaces, Dynamic Modeling, Multi-variable Systems

14:00-14:20	TuB3.4

Optimal Operation and Stabilising Control of the Concentric Heat-Integrated Distillation Column, pp. 747-752

Bisgaard, Thomas	Tech. Univ. of Denmark
Skogestad, Sigurd	Norwegian Univ. of Science & Tech. (NTNU)
Huusom, Jakob Kjøbsted	Tech. Univ. of Denmark
Abildskov, Jens	Tech. Univ. of Denmark

A systematic control structure design method is applied on the concentric heat-integrated distillation column (HIDiC) separating benzene and toluene. A degrees of freedom analysis is provided for identifying potential manipulated and controlled variables. Optimal operation is mapped and active constraints are identified for constructing the supervisory control layer. The fundamental problem of obtaining a stabilising control structure is addressed resulting in the regulatory control layer design. A supervisory control layer is devised and combined with the regulatory control layer. The control structure is finally evaluated by dynamic simulation for proving an acceptable performance.

TuB4	Room T2

Modeling and Control Techniques for Artificial Pancreas Systems (Invited Session)

Chair: Cinar, Ali	Illinois Inst. of Tech
Co-Chair: Dassau, Eyal	Harvard Univ
Organizer: Cinar, Ali	Illinois Inst. of Tech

13:00-13:20	TuB4.1

Hybrid Online Sensor Error Detection and Functional Redundancy for Artificial Pancreas Control Systems (I), pp. 753-758

Feng, Jianyuan	Illinois Inst. of Tech
Turksoy, Kamuran	Illinois Inst. of Tech
Samadi, Sediqeh	Illinois Inst. of Tech
Hajizadeh, Iman	Illinois Inst. of Tech
Cinar, Ali	Illinois Inst. of Tech

Artificial pancreas (AP) control systems rely on signals from glucose sensors to collect glucose concentration (GC) information from people with Type 1 diabetes and compute insulin infusion rates to maintain GC within a desired range. Sensor performance is often limited by sensor errors, communication interruptions and noise. A hybrid online sensor error detection and functional redundancy system is developed to detect errors in online signals, and replace erroneous or missing values detected with model-based estimates. The proposed hybrid system relies on two techniques, an outlier-robust Kalman filter (ORKF) and a locally-weighted partial least squares (LW-PLS) regression model. This leverages the advantages of automatic measurement error elimination with ORKF and data-driven prediction with LW-PLS. A novel method called nominal angle analysis is proposed to distinguish between signal faults and large changes in sensor values caused by real dynamic changes in the metabolism. The performance of the system is illustrated with clinical data from continuous glucose monitoring sensors collected from people with Type 1 diabetes.

13:20-13:40	TuB4.2

Model Identification Using Continuous Glucose Monitoring Data for Type 1 Diabetes (I), pp. 759-764

Boiroux, Dimitri	Tech. Univ. of Denmark
Hagdrup, Morten	Tech. Univ. of Denmark
Mahmoudi, Zeinab	Tech. Univ. of Denmark
Poulsen, Niels Kjølstad	Tech. Univ. of Denmark
Madsen, Henrik	Tech. Univ. of Denmark
Jorgensen, John Bagterp	Tech. Univ. of Denmark

This paper addresses model identification of continuous-discrete nonlinear models for people with type 1 diabetes using sampled data from a continuous glucose monitor (CGM). We compare five identification techniques: least squares, weighted least squares, Huber regression, maximum likelihood with extended Kalman filter and maximum likelihood with unscented Kalman filter. We perform the identification on a 24-hour simulation of a stochastic differential equation (SDE) version of the Medtronic Virtual Patient (MVP) model including process and output noise. We compare the fits with the actual CGM signal, as well as the short- and long-term predictions for each identified model. The numerical results show that the maximum likelihood-based identification techniques offer the best performance in terms of fitting and prediction. Moreover, they have other advantages compared to ODE-based modeling, such as parameter tracking, population modeling and handling of outliers.

13:40-14:00	TuB4.3

The Artificial Pancreas: A Dynamic Challenge (I), pp. 765-772

Stavdahl, Øyvind	Norwegian Univ. of Science & Tech. (NTNU)
Fougner, Anders Lyngvi	Norwegian Univ. of Science & Tech. (NTNU)
Kölle, Konstanze	Norwegian Univ. of Science & Tech. (NTNU)
Christiansen, Sverre Christian	Norwegian Univ. of Science & Tech. (NTNU)
Ellingsen, Reinold	Norwegian Univ. of Science & Tech. (NTNU)
Carlsen, Sven Magnus	Norwegian Univ. of Science & Tech. (NTNU)

In patients with diabetes mellitus type 1, the pancreatic insulin production ceases, causing raise in blood glucose level (BGL) and potentially severe long-time complications. The holy grail of diabetes treatment is the artificial pancreas (AP), a closed-loop control system that replaces the missing regulation of the user's BGL by infusing insulin, and possibly glucagon. Numerous attempts have been largely unsuccessful, mainly due to slow dynamics, which limits the attainable closed-loop control performance and robustness. System performance has been

improved through new sensor technology and faster-acting insulin types, but the risk of hypoglycemia is still significant unless the glucose setpoint is placed at an unnaturally high level.

We argue that this problem is mainly caused by inappropriate sites chosen for glucose measurement and insulin infusion. While intravascular measurement and infusion provides the fastest dynamics possible and thus the best conditions for closed-loop control, it is only viable in inpatients mainly due to danger of infections and limited sensor durability. On the other extreme, state-of-the-art subcutaneous (SC) systems exhibit substantial time delays and diffusion dynamics, yielding poor BGL control in the event of disturbances from e.g. meals and physical activity. In order to avoid dangerous hypoglycemia it is therefore arguably impossible to avoid daily episodes of elevated BGL (typically 10–15 mmol/L) that increases the risk of long-term complications. Furthermore, the slow insulin uptake from subcutis remains as a major challenge. Hence we advocate another route: the double intraperitoneal (IP) AP. Here, insulin is released into the abdominal cavity (peritoneum) through a semi-permanent port, which also allows access for IP glucose sensing. This improves both sensing and absorption dynamics. Thus the closed-loop control may be significantly tighter, allowing a setpoint closer to the healthy normal BGL of approximately 4.5 mmol/L whilst potentially improving system safety. These statements are supported by results from our own research and the literature.

14:00-14:20 TuB4.4

Retrospective Optimization of Daily Insulin Therapy Parameters: Control Subject to a Regenerative Disturbance Process (I), pp. 773-778

Patek, Stephen D. — Univ. of Virginia
Lv, Dayu — Univ. of Virginia
Campos-Nanez, Enrique — Univ. of Virginia
Breton, Marc D — Univ. of Virginia

This paper develops a novel approach to data-driven optimization of insulin pump treatment parameters in Type 1 Diabetes (T1D). In this approach, records of continuous glucose monitoring (CGM), insulin delivery, and meal records are used (i) to retrospectively estimate samples of the disturbance process that is responsible for daily variability in blood glucose and (ii) to optimize the parameters of functional insulin therapy (i.e. the patient's basal rate, correction factor, and carbohydrate ratio profiles) against the ensemble of estimated disturbance process samples. We illustrate the proposed methodology through retrospective application to data collected in a 30-day field study of patients with T1D, as well as through in silico pre-clinical trials using the FDA-accepted Virginia / Padova Type 1 Simulator.

14:20-14:40 TuB4.5

Shaping the MPC Cost Function for Superior Automated Glucose Control (I), pp. 779-784

Lee, Joon Bok — Univ. of California, Santa Barbara
Gondhalekar, Ravi — Harvard Univ
Dassau, Eyal — Harvard Univ
Doyle, Francis — Harvard Univ

The properties of an objective function are fundamental to the functionality of a model predictive controller (MPC). In automated glucose control, avoidance of hypo- and hyperglycemia introduces significant challenges in the design of this cost function. We present a new formulation of the cost function for an MPC based on clinical requirements, and validate the algorithm under in silico and advisory mode assessments. The proposed formulation exhibits significant improvements in avoiding hypoglycemia, compared to clinically validated controllers, and can also mitigate hyperglycemia, across a wide range of in silico scenarios as well as glucose responses seen in actual clinical settings.

14:40-15:00 TuB4.6

An Automatic Denoising Method with Estimation of Noise Level and Detection of Noise Variability in Continuous Glucose Monitoring, pp. 785-790

Zhao, Hong — Zhejiang Univ
Zhao, Chunhui — Zhejiang Univ

Although continuous glucose monitoring (CGM) devices have been the crucial part of the artificial pancreas, their success has been discounted by random measurement noise. The difficulty of denoising methods for CGM is that the filter parameters are hard to be determined to well reflect the real noise level. Besides, the noise level may show both intraindividual and interindividual variability which thus requires that the filter parameters should be adjusted to follow the noise changes. In this paper, we proposed an automatic denoising method which covers two important components. On the one hand, the noise level can be estimated so that the filter parameters are determined properly. On the other hand, the variability of signal-to-noise ratio can be detected for self-adjustment of filter parameters. First, the noise level is evaluated using expectation maximization algorithm which can fix proper filter parameters for the current signals. Second, a confidence interval is defined by computing the power spectral density (PSD) of the CGM signals to identify the changes of noise level which can tell whether or not the parameters of Kalman filter (KF) should be adjusted. The above issues are investigated based on thirty in silico subjects. The proposed method can work well to identify the changes of noise level and determine proper filter parameters.

TuC1 Room T2

Optimization in Systems Biotechnology and Systems Medicine (Invited Session)

Chair: Jacobsen, Elling — KTH Royal Inst. of Tech
Co-Chair: Findeisen, Rolf — Otto-Von-Guericke-Univ. Magdeburg
Organizer: Waldherr, Steffen — Otto-Von-Guericke-Univ. Magdeburg
Organizer: Jacobsen, Elling — KTH Royal Inst. of Tech
Organizer: Findeisen, Rolf — Otto-Von-Guericke-Univ. Magdeburg

15:30-15:50 TuC1.1

Dynamic Flux Balance Analysis of the Metabolism of Microalgae under a Diurnal Light Cycle (I), pp. 791-796

Baroukh, Caroline — INRA
Steyer, Jean-Philippe — INRA
Bernard, Olivier — INRIA
Chachuat, Benoit — Imperial Coll. London

Microalgae have received much attention in the context of renewable fuel production, due to their ability to produce in high quantities carbon storage molecules such as lipids and carbohydrates. Despite significant research effort over the last decade, the production yields remain low and need to be optimized. For that, a thorough understanding of carbon storage metabolism is necessary. This paper develops a constrained metabolic model based on the dFBA framework to represent the dynamics of carbon storage in microalgae under a diurnal light cycle. The main assumption here is that microalgae adapt their metabolism in order to optimize their production of functional biomass (proteins, membrane lipids, DNA, RNA) over a diurnal cycle. A generic metabolic network comprised of 160 reactions representing the main carbon and nitrogen pathways of microalgae is used to characterize the metabolism. The optimization problem is simplified by exploiting the right kernel of the stoichiometric matrix, and transformed into a linear program by discretizing the differential equations using a classical collocation technique. Several constraints are investigated. The results suggest that the experimentally observed strategy of accumulation of carbon storage molecules during the day, followed by their depletion during the night may indeed be the optimal one. However, a constraint on the maximal synthesis rate of functional biomass must be added for consistency with the biological observations.

15:50-16:10 TuC1.2

A Set-Based Optimal Control Approach for Pharmacokinetic / Pharmacodynamic Drug Dosage Design

(I), pp. 797-802

Lucia, Sergio	Otto-Von-Guericke-Univ. Magdeburg
Schliemann-Bullinger, Monica	Otto-Von-Guericke Univ. Magdeburg
Findeisen, Rolf	Otto-Von-Guericke-Univ. Magdeburg
Bullinger, Eric	Otto-Von-Guericke Univ. Magdeburg

Robust optimal control of pharmacokinetic / pharmacodynamic (PK/PD) models allows for optimal drug dosage design under model uncertainties. Typical PK/PD models are highly uncertain and therefore a robust design of the drug dosage is necessary to guarantee that important health-related constraints are satisfied for all the possible values of the uncertainty. This paper shows that the responses of a simple class of PK/PD models are monotonous in the parameters and in the input. This greatly simplifies the design of a scenario-based nonlinear model predictive controller as just two scenarios are necessary to fully bound the system responses. This is illustrated with the drug dosage design for a model of erythropoietin injection, in which we also show the potential benefit of having intermediate measurements during the application of the therapy.

16:10-16:30 TuC1.3

A Two-Loop Optimization Strategy for Multi-Objective Optimal Experimental Design (I), pp. 803-808

Yu, Hui	Univ. of Strathclyde
Yue, Hong	Univ. of Strathclyde
Halling, Peter	Univ. of Strathclyde

A new strategy of optimal experimental design (OED) is proposed for a kinetically controlled synthesis system by considering both the observation design and the input design. The observation design that combines sampling scheduling and measurement set selection is treated as a single optimization problem arranged in the inner loop, while the optimization of the input intensities is conducted in the outer loop. This multi-objective dynamic optimization problem is solved via the integration of the particle swarm algorithm (for the outer loop) and the interior-point method (for the inner loop). Numerical studies demonstrate the efficiency of this optimization strategy and show the effectiveness of this integrated OED in reducing parameter estimation uncertainties. In addition, process optimization of the case study enzyme reaction system is investigated with the aim to obtain the maximum production rate by taking into account of the experimental cost.

16:30-16:50 TuC1.4

Exploring Design Principles of Gene Regulatory Networks Via Pareto Optimality (I), pp. 809-814

Otero-Muras, Irene	IIM-CSIC
Banga, Julio R.	IIM-CSIC (Spanish Council for Scientific Res

One central problem in systems and synthetic biology is to characterize the biological functions of regulatory network motifs. Here we consider recent model-based exploration approaches used to identify motifs capable of performing a specific biological task. In this work, we propose an optimization based strategy where the motivation is twofold: on the one hand, to introduce efficiency and optimality in the search, by using global mixed integer nonlinear optimization methods. On the other hand, to incorporate multiple design objectives (Pareto optimality), in order to cope with realistic trade-offs observed in nature. The potential of this approach is illustrated through an example where we explore the design principles underlying stripe-forming motifs.

16:50-17:10 TuC1.5

Robust Target Identification for Drug Discovery (I), pp. 815-820

Jacobsen, Elling	KTH Royal Inst. of Tech
Nordling, Torbjörn E.M.	National Cheng Kung Univ

A key step in the development of new pharmaceutical drugs is that of identifying direct targets of the bioactive compounds, and distinguishing these from all other gene products that respond indirectly to the drug targets. Currently dominating approaches to this problem are based on often time consuming and costly experimental methods aimed at locating physical bindings of the corresponding small molecule to proteins or DNA sequences. In this paper we consider target identification based on time-series expression data of the corresponding gene regulatory network, using perturbation with the active compound only. As we show, the problem of identifying the direct targets can then be cast as a linear regression problem and, in principle, be accomplished with a number of samples equal to the number of involved genes and bioactive compounds. However, the regression matrix will typically be highly ill-conditioned and the target identification therefore prone even to small measurement uncertainties. In order to provide a label of confidence for the target identification, we consider conditions that can be used to quantify the robustness of the identification of individual drug targets with respect to uncertainty in the expression data. For this purpose, we cast the uncertain regression problem as a robust rank problem and employ SVD or the structured singular value to compute the robust rank. The proposed method is illustrated by application to a small scale gene regulatory network synthesised in yeast to serve as a benchmark problem in network inference.

17:10-17:30 TuC1.6

Optimization Alternatives for Robust Model-Based Design of Synthetic Biological Circuits, pp. 821-826

Boada, Yadira	Univ. Pol. De València
Pitarch, Jose Luis	Univ. De Valladolid
Vignoni, Alejandro	Max Planck Inst. of Molecular Cell Biology and Genetics
Reynoso-Meza, Gilberto	Pontificia Univ. Católica De Paraná
Picó, Jesús	Univ. Pol. De Valencia

Synthetic biology is reaching the situation where tuning devices by hand is no longer possible due to the complexity of the biological circuits being designed. Thus, mathematical models need to be used in order, not only to predict the behavior of the designed synthetic devices; but to help on the selection of the biological parts, i.e., guidelines for the experimental implementation. However, since uncertainties are inherent to biology, the desired dynamics for the circuit usually requires a trade-off among several goals. Hence, a multi-objective optimization design (MOOD) naturally arises to get a suitable parametrization (or range) of the required kinetic parameters to build a biological device with some desired properties. Biologists have classically addressed this problem by evaluating a set of random Monte Carlo simulations with parameters between an operation range. In this paper, we propose solving the MOOD by means of dynamic programming using both a global multi-objective evolutionary algorithm (MOEA) and a local gradient-based nonlinear programming (NLP) solver. The performance of both alternatives is then checked in the design of a well-known biological circuit: a genetic incoherent feed-forward loop showing adaptive behavior.

TuC2 Room T1

Energy and Power Systems (Invited Session)

Chair: Foss, Bjarne	Norwegian Univ. of Science & Tech. (NTNU)
Co-Chair: Knudsen, Brage Rugstad	Norwegian Univ. of Science & Tech. (NTNU)
Organizer: Knudsen, Brage Rugstad	Norwegian Univ. of Science & Tech. (NTNU)
Organizer: Foss, Bjarne	Norwegian Univ. of Science & Tech. (NTNU)

15:30-15:50 TuC2.1

Optimal Health-Aware Charging Protocol for Lithium-Ion Batteries: A Fast Model Predictive Control Approach (I), pp. 827-832

Torchio, Marcello	Univ. Degli Studi Di Pavia

Magni, Lalo	Univ. of Pavia
Braatz, Richard D.	Massachusetts Inst. of Tech
Raimondo, Davide Martino	Univ. Degli Studi Di Pavia

Lithium-ion batteries are widely used in industry to supply different portable applications. Their management is handled by Battery Management Systems (BMSs), which are intended to ensure good performance (such as minimum charging time) while simultaneously minimizing safety risks. The use of accurate mathematical models can help in achieving such goals. The first-principles pseudo-two dimensional (P2D) model is one of the mostly used models for simulation but rarely used in design of BMSs. This model, together with a description of the capacity fade mechanisms occurring during battery operations, is used to design health-aware BMS strategies. A Model Predictive Control (MPC) scheme based on a linearized version of the P2D model is proposed in order to track a reference value of the State of Charge (SOC), while taking into account the aging dynamics of the system as well as temperature and voltage constraints. Simulations show the effectiveness of the approach: the tuning of the control parameters allows controlled operation with different tradeoffs between charging time and battery lifetime enhancement.

15:50-16:10 TuC2.2

Economic Dispatch for Microgrids with Constrained External Power Exchange (I), pp. 833-838

Zachar, Michael	Univ. of Minnesota
Daoutidis, Prodromos	Univ. of Minnesota

This paper examines microgrid unit dispatch, with hourly bounds on energy exchange with the macrogrid and minimum storage level constraints. These goals can be used to meet market constraints and to ensure there is sufficient energy reserved for future periods, respectively. In particular, economic model predictive control is used to minimize cost while ensuring these scheduling goals and other operational constraints are satisfied. Simulation of a dynamic microgrid system over a 24-hour period shows that the proposed dispatch strategy is able to effectively reject forecasting errors and meet the established energy exchange and storage level goals.

16:10-16:30 TuC2.3

Simulation and Design Methods for Multiphase Multistream Heat Exchangers (I), pp. 839-844

Watson, Harry	Massachusetts Inst. of Tech
Barton, Paul	Massachusetts Inst. of Tech

Multistream heat exchangers (MHEXs) are found in many energy intensive and industrially relevant cryogenic processes. However, design and optimization of such processes is rendered difficult by the inability to simulate MHEXs robustly, as most current flowsheet-level MHEX models solve only an energy balance with no constraint on second law feasibility. The new model described herein combines an extension of the classical pinch analysis algorithm with explicit dependence on the heat exchange area to formulate a nonsmooth equation system which can be solved for up to three unknown variables in an MHEX. The resulting model is further augmented to simulate realistic thermodynamic phenomena, such as phase change and equilibrium, which are also naturally described by additional nonsmooth equations.

16:30-16:50 TuC2.4

Self-Optimizing Control of a Two-Stage Refrigeration Cycle (I), pp. 845-850

Verheyleweghen, Adriaen	Norwegian Univ. of Science & Tech. (NTNU)
Jäschke, Johannes	Norwegian Univ. of Science & Tech. (NTNU)

The application of self-optimizing control theory to a two-stage refrigeration cycle was investigated. Defining the cost function as the economical trade-off between the power consumption and the evaporator outlet temperatures, it was found that the optimal point of operation leaves two unconstrained degrees of freedom for implementing a self-optimizing control structure. We consider two cases: (1) where the self-optimizing control structure is designed to optimally reject only physical process disturbances, and (2) where the control structure in addition handles changes in the economic parameters of the cost function. The control structure is able to keep the process close to optimal despite disturbances and changes in the product prices, and thus makes a supervisory real-time optimization (RTO) layer unnecessary.

16:50-17:10 TuC2.5

Modifier Adaptation Approach to Deal with Structural and Parametric Uncertainty (I), pp. 851-856

Rodríguez-Blanco, Tania	Univ. of Valladolid
Sarabia, Daniel	Univ. of Burgos
de Prada, Cesar	Univ. of Valladolid

Real-Time Optimization (RTO) is not always able to achieve optimal process operation due to the presence of significant uncertainty about the plant models that are used to make decisions and also due to the differences between control architecture layers which operate on different time-scales and use different kind of models.To overcome these issues the economic optimization problem is modified following the Modifier Adaptation methodology to bring the process to the real optimum despite the presence of uncertainty by using plant measurements.

To deal with parametric and structural plant-model mismatch, a new approach is presented that combines the estimation of process gradients from transient and steady-state information. It speeds up the convergence of Modifier Adaptation methodology to the process optimum. The approach is illustrated through the simulated example of a depropanizer distillation column.

17:10-17:30 TuC2.6

Economic Optimization of Sawmill Residues Collection for Bioenergy Conversion (I), pp. 857-862

Zamar, David Sebastian	Univ. of British Columbia
Gopaluni, Bhushan	Univ. of British Columbia
Sokhansanj, Shahab	Department of Chemical and Biological Engineering, Univ. Of
Ebadian, Mahmood	Department of Chemical and Biological Engineering, Univ. Of

The collection of sawmill residuals is an important logistic activity for the pulp and paper industry, which use the biomass as a source of energy. We study a vehicle routing problem for a network composed of a single depot and 25 nearby sawmills in the Lower Mainland region of British Columbia, Canada. The sawmills serve as potential suppliers of residual biomass to the depot, which in turn processes and distributes the sawmill residuals to the pulp and paper mills. This problem consists of identifying the best daily routing schedule for a fixed number of vehicles. The objective is to maximize the ratio of residual dry tonnes collected to kilometers traveled, while achieving a minimum daily amount of residual dry mass. There are several random components in the problem, including the availability and moisture content of the residuals as well as the time spent on the road to retrieve the residuals. We use a combination of scenario analysis and heuristics to solve this stochastic vehicle routing problem (SPVRP).

TuC3	Room T4
Modelling and System Identification I (Regular Session)	
Chair: Baratti, Roberto	Univ. Degli Studi Di Cagliari
Co-Chair: Liu, Tao	Dalian Univ. of Tech

15:30-15:50 TuC3.1

Output Error Model Identification against Unexpected Load Disturbance, pp. 863-868

Dong, Shijian	Dalian Univ. of Tech
Liu, Tao	Dalian Univ. of Tech
Chen, Fengwei	Univ. of Lorraine

An output error model identification method is proposed for industrial processes with time delay under unexpected load disturbance. By regarding the output response to load disturbance as a time-varying parameter for estimation, a least-squares identification algorithm is developed to simultaneously estimate all the model parameters including the time delay together with the load disturbance response. An auxiliary model is used to guarantee consistent estimation of the process model parameters. Moreover, dual forgetting factors are introduced to improve the convergence rates of estimating the model parameters and the load disturbance response, respectively. The convergence of parameter estimation is analyzed with a strict proof. A benchmark example from the literature is used to demonstrate the effectiveness and merit of the proposed identification method.

15:50-16:10	TuC3.2

Dynamics of Nonlinear Chemical Process with Multiplicative Stochastic Noise, pp. 869-874

Baratti, Roberto	Univ. Degli Studi Di Cagliari
Tronci, Stefania	Univ. Degli Studi Di Cagliari
Schaum, Alexander	Christian-Albrechts Univ. Zu Kiel
Alvarez, Jesus	Univ. Autonoma Metropolitana

Motivated by problems in process design, monitoring and control, the effect of multiplicative stochastic uncertainty injection on the behavior of nonlinear dynamical system is studied with Fokker Plank theory for two rather simple case examples selected to draw rigorous results with analytic formulae. The effect of noise multiplicativeness on the shape of the stationary state PDF and of the transient one along deterministic, probability diffusion, and escape time scales is characterized. The findings are corroborated and illustrated with numerical simulations. The results provide insight to assist the improvement of numerical Monte Carlo and polynomial chaos methods for stochastic multi-state multi-noise dynamical chemical processes underlien by complex nonlinear behavior.

16:10-16:30	TuC3.3

Gas Phase Train in Upstream Oil & Gas Fields: PART-I Model Development, pp. 875-881

Al-Naumani, Yahya Hamood	Univ. of Sheffield
Rossiter, J. Anthony	Univ. of Sheffield
Al-Bahlawi, Said	Petroleum Development Oman

The prime contribution of this paper is to provide a large scale system (LSS) model for the gas phase operation in upstream oil and gas plants. The process model consists of the three main gas conditioning processes which exist in most upstream oil and gas processing plants; these are gas sweetening, gas dehydration, and hydrocarbon dew-pointing. The function of such a model is to provide a realistic process representation to test and verify different process control approaches, specifically those which deal with highly interactive control loops.

16:30-16:50	TuC3.4

Discrete-Time Optimal Control of Electric Hot Water Tank, pp. 882-888

Beeker, Nathanael	MINES ParisTech
Malisani, Paul	EDF Lab
Petit, Nicolas	MINES ParisTech

The paper exposes a discrete time model with three states to represent the dynamics of an Electric Hot Water Tank (EHWT). This models stands halfway between distributed parameters equations and totally lumped single integrators. It allows a faithful reproduction of observed behaviors, especially those induced by stratification. It is also instrumental in formulating optimal control problems aiming at maximizing performance under comfort constraints. In particular, it is shown how to recast such problems as a Mixed-Integer Linear Program (MILP) so that the problem can be solved with off-the-shelf software packages. Numerical results are presented.

16:50-17:10	TuC3.5

Online Optimal Experiment Design: Reduction of the Number of Variables, pp. 889-894

Lemoine-Nava, Jose Roberto	TU Dortmund
Walter, Sebastian	Univ. Heidelberg
Körkel, Stefan	Univ. Heidelberg
Engell, Sebastian	TU Dortmund

In this work, a method for reducing the number of degrees of freedom in online optimal dynamic experiment design problems for systems described by differential equations is proposed. The online problems are posed such that only the inputs which extend an operation policy resulting from an experiment designed offline are optimized. This is done by formulating them as multiple experiment designs, considering explicitly the information of the experiment designed offline and possible time delays unknown a priori. The performance of the method is shown for the case of the separation of isopropanolol isomers in a Simulated Moving Bed plant.

17:10-17:30	TuC3.6

Modelling and Design of Carbon Dioxide Absorption in Rotating Packed Bed and Packed Column, pp. 895-900

Thiel, Matthias	RWTH Aachen Univ
Wong, David, S.H.	National Tsing-Hua Univ
Yu, Cheng-Hsiu	National Tsing Hua Univ
Kang, Jia-Lin	National Tsing-Hua Univ
Jang, Shi-Shang	National Tsing-Hua Univ
Tan, Chung-San	National Tsing Hua Univ

This study compares the carbon dioxide capture efficiency of packed bed (PB) column and rotating packed bed (RPB) absorber by mono-ethanolamine (MEA) solution. Carbon dioxide absorption experiments were carried out in laboratory scale packed bed column and rotating packed bed at various lean carbon dioxide loadings of the MEA solution. They were modelled successfully by an ASPEN Plus advanced customer model (ACM). Using these models, we found that substantial savings of packing volume can be achieved using a series arrangement of RPB and PB for the CO2 capture process using 30wt% MEA solution.

TuC4	Room T3
Control Applications II (Regular Session)	
Chair: Puschke, Jennifer	RWTH Aachen Univ

15:30-15:50	TuC4.1

Robust Control of a Supermarket Refrigeration System Using Multi-Stage NMPC, pp. 901-906

Subramanian, Sankaranarayanan	TU Dortmund
Ahmad, Adeel	TU Dortmund
Engell, Sebastian	TU Dortmund

Using Nonlinear Model Predictive Control (NMPC), real world systems that are subject to stringent constraints can be controlled efficiently when accurate plant models are employed. Model uncertainties however may lead to poor performance of the controller and to constraint violations because of the wrong predictions. As in real applications, there often is a significant plant model mismatch, the controller must be robust to plant-model mismatch without deteriorating the performance of the controller significantly. Multi-stage NMPC is a robust scheme which has been proven to be less conservative than open loop worst case solutions because of the presence of feedback information at the future time stages is explicitly accounted in the problem formulation. In this paper, we study the application of this NMPC technique to a supermarket refrigeration system under uncertainty and show that the presence of uncertainties in the model lead to constraint violations when standard NMPC scheme is applied. The robust multi-stage NMPC scheme improves the controller performance by accounting for the uncertainties in the prediction and results in a reliable operation of the system.

15:50-16:10	TuC4.2

Robust Dynamic Optimization of a Semi-Batch Emulsion Polymerization Process with Parametric Uncertainties - a Heuristic Approach -, pp. 907-912

Puschke, Jennifer	RWTH Aachen Univ
Mitsos, Alexander	RWTH Aachen Univ

Optimized exothermic semi-batch emulsion polymerization typically exhibits active arcs of the constraints for the reactor temperature. Given parametric uncertainties in the process model, this might lead to constraint violations which are a safety concern. Therefore, an approach is investigated, such that constraint violations are less likely and is hence robust feasible. The two-model approach is presented as an approximate solution. Therein, two models, the nominal and a worst-case model are optimized simultaneously. Because of the challenges in defining the worst-case, a heuristic method is presented to define the worst-case parameter and its parameter value. The results of the process optimization with the two-model approach are compared with the results of the optimization with the nominal model solely. In addition the feasibility of both optimization strategies is compared by simulating hundred different scenarios with random parameter values from the uncertainty set. The presented approximation does not guarantee robust feasibility, but path constraint violations are less likely due to the introduced conservatism compared to the original optimization.

16:10-16:30 TuC4.3

Neural NLMPC Schemes for the Control of the Activated Sludge Process, pp. 913-918

Goldar Davila, Alejandro	Univ. Simón Bolívar
Revollar, Silvana	Univ. of Salamanca
Lamanna, Rosalba	Univ. Simón Bolívar
Vega, Pastora	Univ. of Salamanca

Nonlinear model predictive controllers based on neural networks are implemented in this paper to regulate the activated-sludge process. The simulation protocol BSM1 is used to apply the predictive controller schemes and study the closed loop process behavior in different situations. Also input-output data are gathered from the benchmark for the neural networks training. Control results under dry-weather perturbations are satisfactory when a combined NLMPC – Classic PI control system is tested. This scheme has shown the best performance when compared to a centralized NLMPC scheme, a decoupled NLMPC scheme or the classic PI system developed on the BSM1. An economic analysis indicates that the neural predictive algorithm for nitrates concentration control improves the effluent quality while also decreasing the pumping energy consumption by optimizing the internal recirculation flowrate variations.

16:30-16:50 TuC4.4

Robust PID Auto-Tuning for the Quadruple Tank System, pp. 919-924

Ionescu, Clara	Ghent Univ
Maxim, Anca	Tech. Univ. of Iasi
Copot, Cosmin	Ghent Univ
De Keyser, Robin M.C.	Ghent Univ

In multi-modular process architectures with independent but interacting sub-systems, identification may not be the first choice at hand for closed loop control. A robust relay-based PID autotuning strategy is presented and validated on a quadruple tank system with non-minimum phase dynamics. The controller ensures a specified closed loop robustness, which is of great benefit to the overall performance. The experimental results suggest that the proposed method fulfills the robustness requirement and performs well in various operating conditions of the testbench.

16:50-17:10 TuC4.5

Open Loop Optimal Operation and Sensitivity Analysis of a Continuous Biobutanol Fermentation Process with Ex-Situ Adsorption Recovery, pp. 925-930

Kim, Boeun	KAIST
Jang, Hong	KAIST
Lee, Jay H.	KAIST

Biobutanol is considered to be an attractive biofuel due to its chemical similarity to gasoline, but low fermentation performance caused by butanol toxicity stands as a major obstacle in taking it to full commercialization. As a solution, an ex-situ recovery system with periodically switched adsorption column can be used to maintain the butanol concentration in a fermenter below the critical level. Due to the complex nature of the operation manifested by the periodic operation and the resulting cyclic steady state (CSS), it becomes a challenge to determine the optimal operation strategy of the system. In this study, an optimization problem is formulated to determine the operating condition to maximize a profit function at the CSS for a given feed concentration. This is followed by an open-loop sensitivity analysis to investigate the effect of uncertainties in the model parameters and adsorbent states on performance of the determined recipe.

17:10-17:30 TuC4.6

A Two-Layer Structure for Stabilization and Optimization of an Oil Gathering Network, pp. 931-936

Codas, Andrés	Norwegian Univ. of Science & Tech. (NTNU)
Jahanshahi, Esmaeil	Norwegian Univ. of Science & Tech. (NTNU)
Foss, Bjarne	Norwegian Univ. of Science & Tech. (NTNU)

In this work, we present the control and optimization of a network consisting of two gas-lifted oil wells, a common pipeline-riser system and a separator. The gas-lifted oil wells may be open-loop unstable. The regulatory layer stabilizes the system by cascade control of wellhead pressure measurements without needing bottom hole sensing devices. An economic Nonlinear Model Predictive Control (NMPC) based on the Multiple Shooting (MS) formulation is applied for optimization of the network operations. The optimization layer thus provides optimal settings for the regulatory controllers. The control structure has been validated by using the realistic OLGA simulator as the process, and using simplified models for Kalman filtering and the NMPC design. The simplified models are implemented in Modelica and fit to the Olga model to represent the main dynamics of the system. The proposed two-layer controller was able to stabilize the system and increase the economical outcome.

WePL	Room T1
Plenary III Vassily Hatzimanikatis: "Analysis and Design of Metabolic Networks under Uncertainty" (Plenary Session)	
Chair: Budman, Hector M.	Univ. of Waterloo
Co-Chair: Smets, Ilse	KU Leuven, Department of Chemical Engineering, CREaS

08:15-09:10	WePL.1

*Analysis and Design of Metabolic Networks under Uncertainty**

Hatzimanikatis, Vassily	EPFL

Metabolic engineering and synthetic biology involve the design and retrofitting of genome-scale metabolic networks through the manipulation of enzyme activities. Efficient design requires the use of mathematical models that account for the reaction mechanisms of the enzymes, and their thermodynamic and kinetic properties. We present the recent developments of a workflow for the development of genome-scale kinetic models of metabolic networks. The workflow is called ORACLE (Optimization and Risk Analysis of Complex Living Entities) and it accounts for the uncertainty and incompleteness of the available experimental information used in model development and parametrization.

ORACLE addresses the following fundamental problem:

Given:

(a) a set of observed conditions of cellular physiology,

(b) a genome-scale stoichiometric model of metabolism,

(c) a (partial) flux profile in this network associated with the physiological conditions, and

(d) a (partial) profile of metabolite concentrations

find

a family of nonlinear kinetic models and the associated distribution of the kinetic parameters that are consistent with the information above.

The availability of kinetic models of metabolic networks allows the development and application of methods from optimization, dynamics and control of process systems approaches for analysis and design. We will demonstrate the application of ORACLE for the design and optimization of the production of industrial chemicals by E. coli and S. cerevisiae.

WeK1N1	Room T2
Keynote V (Semi-Plenary Session)	
Chair: Budman, Hector M.	Univ. of Waterloo
Co-Chair: Mauricio-Iglesias, Miguel	Univ. De Santiago De Compostela

09:15-09:45	WeK1N1.1

A Multi-Scale Model of the Whole Human Body Based on Dynamic Parsimonious Flux Balance Analysis, pp. 937-942

Khaksar Toroghi, Masood	Univ. of Toronto
Cluett, William	Univ. of Toronto
Mahadevan, Radhakrishnan	Univ. of Toronto

The multi-scale modelling approach is a powerful mathematical technique for simulating and analyzing complex biological systems such as the human body. This tool can help study the interactions of the various networks in a living organism, from the cellular level up to the population scale, in one framework. In this paper, a generic mathematical model is developed that describes human metabolism with 237 serum metabolites integrated with a chosen set of human metabolic networks. A new computational approach is presented for solving the resulting dynamic problem using parsimonious flux balance analysis (pFBA). To illustrate the performance of the proposed approach, the human hepatocyte genome scale model is selected for the metabolic network to be included. The simulation results show that the proposed approach has promise with respect to both computational efficiency and convergence. To demonstrate the potential application of the developed model, prediction of amino acid biomarkers for a set of inborn errors of metabolism (IEM) is considered as an example. All the simulations are performed using MATLAB and the COBRA toolbox. This framework has the potential to simulate various human metabolic disorders to help with the diagnosis of associated human diseases and to suggest novel treatment strategies. In addition, it opens the door to new opportunities for personalized medicine.

WeK1N2	Room T1
Keynote VI (Semi-Plenary Session)	
Chair: Alvarez, Jesus	Univ. Autonoma Metropolitana
Co-Chair: de Prada, Cesar	Univ. of Valladolid

09:15-09:45	WeK1N2.1

Stability of Multi-Phase Systems Evolving on an Equilibrium Manifold, pp. 943-948

Ydstie, B. Erik	Carnegie Mellon Univ

The paper extends Gibbs tangent plane theory for equilibrium (infinite time) systems to a limited class of non-equilibrium (finite time) systems. The class of systems we consider have dynamics constrained to an equilibrium manifold defined by contact between the entropy and its supporting hyper-plane. It is established that points on the manifold are stabilized provided the degrees of freedom (boundary conditions) are chosen appropriately. The result is applied to the multi-component flash. The adiabatic flash with fixed feed conditions, constant molar hold-up and pressure has a unique and stable steady state. However, a flash with fixed product composition and fixed pressure may have multiple steady states.

WeK2N1	Room T1
Keynote VII (Semi-Plenary Session)	
Chair: Pannocchia, Gabriele	Univ. of Pisa
Co-Chair: Budman, Hector M.	Univ. of Waterloo

09:45-10:15	WeK2N1.1

Dynamic Time to Surge Computation for Electric Driven Gas Compressors During Voltage Dips, pp. 949-954

Cortinovis, Andrea	ABB Switzerland Ltd
Mercangöz, Mehmet	ABB Switzerland Ltd
Stava, Tor Olav	Gassco As
Van de Moortel, Sture	ABB Switzerland Ltd
Lunde, Erling	Statoil ASA

This paper investigates the influence of voltage dips on large electric driven gas compressors (EDC) considering a typical application in the oil and gas industry. Voltage or power dips are electric disturbances encountered in EDC which are mainly caused by faults in the electrical grid and might last for durations up to 150ms. For gas compression applications, the loss of driver torque often puts the gas compression process at risk of surge conditions, which is a safety critical constraint. The critical nature of the present problem and the fast dynamics involved, pose challenging requirements for the control and safety systems of the gas compressor and the variable-speed drive system. The main focus of the present paper is the dynamic computation of the time to surge using online information of the estimated motor torque and a process model to predict the future behavior of the compression system. The time to surge can then be used for ride-through or shut-down decisions of the complete system, as well as for manipulating safety valves, e.g. the anti-surge valve. The fulfillment of strict real-time requirements and their direct implications on the complexity of the chosen prediction model and the implementation of the algorithm on an embedded system are also addressed in this article. As an industrial case study, the algorithm is applied to a voltage dip situation using high fidelity simulation data of a compression station.

WeK2N2	Room T2
Keynote VIII (Semi-Plenary Session)	
Chair: Smets, Ilse	KU Leuven, Department of Chemical Engineering, CREaS
Co-Chair: de Prada, Cesar	Univ. of Valladolid

09:45-10:15 WeK2N2.1

Pointwise Innovation–based State Observation of Exothermic Tubular Reactors, pp. 955-960

Schaum, Alexander	Christian-Albrechts Univ. Zu Kiel
Alvarez, Jesus	Univ. Autonoma Metropolitana
Meurer, Thomas	Christian-Albrechts Univ. Zu Kiel
Moreno, Jaime A.	Univ. Nacional Autonoma De Mexico-UNAM

The problem of estimating the spatio-temporal temperature and concentration distribution in a tubular reactor with first order exothermic reaction and in-domain pointwise temperature measurement is considered. The problem is addressed using a simple point innovation structure, which imposes the measurement information at the sensor location in the simulator. Rigorous convergence conditions are presented in dependence of the sensor location and reactor parameters in terms of the dominant eigenvalues of the modified linear transport operators and the Lipschitz constant of the reaction rate. Numerical simulation results show that the proposed approach yields good performance even in the presence of unknown feed temperature perturbations.

WeA1	Room T1
Model Based Control III (Regular Session)	
Co-Chair: GAO, Furong	Hong Kong Univ. of Sci & Tech

10:30-10:50 WeA1.1

Control of a Solar Furnace Using MPC with Integral Action, pp. 961-966

Costa, Bertinho	INESC-ID - IST - ULisbon
Lemos, Joao M.	Inesc-Id
Guillot, Emmanuel	PROMES-CNR, 7 Rue Du Four Solaire, 66120 Font Romeu, Odeillo, Fr

Solar furnaces are devices employed in high temperature material stress tests that use concentrated solar energy. This process has a nonlinear dynamics caused by a fourth power temperature term and by the nonlinear behavior of the shutter. Sun power variability due to weather conditions may affect the operation of a solar furnace if it is not compensated by adjusting the shutter aperture.

The contribution of this paper is to explore and to evaluate the application of model predictive control with integral action to a nonlinear process. Off-line identification is employed to characterize the temperature dynamics. This methodology avoids the use of online adaptation mechanisms that may cause stability problems during temperature stress tests that may melt the material sample. The aim is to design a controller with a good performance, able to track the temperature cycling profile without overshooting to avoid melting the material sample. Active cooling is also explored to improve the temperature tracking during the decrease of the temperature profile. Experimental results obtained from the closed loop control of the plant are presented.

10:50-11:10 WeA1.2

State Estimation and Model Predictive Control for the Systems with Uniform Noise, pp. 967-972

Pavelkova, Lenka	The Inst. of Information Theory and Automation of the CAS
Belda, Kvetoslav	The Inst. of Information Theory and Automation of the CAS

This paper concerns the model predictive control applied to the systems with bounded uncertainties. These systems are described by a state-space model with uniformly distributed states and outputs with unknown bounds of respective distributions. The model matrices are assumed to be known. The approximate estimation of states and noise bounds is based on the Bayesian approach. A state-space generalised predictive control is selected as a suitable target model predictive control strategy. The proposed concept of the above mentioned estimation within generalised predictive control is illustrated by representative comparative simulation examples.

11:10-11:30 WeA1.3

VFA Robust Control of an Anaerobic Digestion Pilot Plant: Experimental Implementation, pp. 973-977

Garcia-Sandoval, Juan Paulo	Univ. of Guadalajara
Méndez-Acosta, Hugo Oscar	Univ. of Guadalajara
Gonzalez-Alvarez, Victor	Univ. of Guadalajara
Alvarez, Jesus	Univ. Autonoma Metropolitana
Schaum, Alexander	Christian-Albrechts Univ. Zu Kiel

In this work, an experimental implementation of a model based output feedback (OF) scheme applied to regulate the volatile fatty acids concentration of an anaerobic digestion pilot plant is presented. The OF scheme was developed within a global nonlinear dynamics framework, resulting in an interlaced control-observer design in the light of passivity, observability, and bifurcation properties. From a industrial control perspective, the resulting OF scheme is a saturated PI controller with: (i) systematic construction and tuning and (ii) nonlocal robust stability conditions in terms of control gains and limits. Experimental results demonstrate the applicability, robustness and reliability of the OF control scheme in a real environment under several load disturbances, severe uncertainties and typical operational failures.

11:30-11:50 WeA1.4

Model Performance Assessment of a Predictive Controller for Propylene/Propane Separation, pp. 978-983

Claro, Erica Rejane Pereira	Braskem S.A
Botelho, Viviane Rodrigues	Federal Univ. of Rio Grande Do Sul
Trierweiler, Jorge Otávio	Federal Univ. of Rio Grande Do Sul
Farenzena, Marcelo	Federal Univ. of Rio Grande Do Sul

This paper presents the results of the model assessment performed on an industrial predictive controller applied to a propylene/propane separation system at Braskem, in Brazil, using the methodology proposed by Botelho *et al.* (2015a, b, c). Besides identifying the controlled variables with modelling uncertainties that were degrading the controller performance, the methodology diagnosed the main cause of the problem, which was related to model-plant mismatch for seven controlled variables, and due to the effect of unmeasured disturbances for other three controlled variables. This diagnosis enabled a more focused approach to the identification work, increasing the productivity of the controller revamp.

11:50-12:10 WeA1.5

'State Déjà Vu' Inter-Agent Learning Adaptive Control Framework, pp. 984-989

Qu, Hongyi	Hong Kong Univ. of Sci & Tech
Zhang, Ridong	Hangzhou Dianzi Univ
Gao, Furong	Hong Kong Univ. of Sci & Tech

An inter-agent learning adaptive control framework is proposed for mass production by using multi-agent system approach to enhance the convergence performance over the single agent control. The idea is to invoke agent-wise differences on estimated parameters of the online estimator in adaptive control. Each agent's estimator selects estimated parameters from a corresponding 'best' agent among them for next iteration according to 'State Déjà vu' criterion mimicking psychological phenomenon of adopting experience from state similar to current one. The application of proposed framework on model free adaptive control shows to have robust convergence, good stability,

and effective performances enhancement.

WeA2	Room T4
Modelling and System Identification II (Regular Session)	
Chair: Samavedham, Lakshminarayanan	National Univ. of Singapore

10:30-10:50 WeA2.1

Machine Learning Based Framework for Multi-Class Diagnosis of Neurodegenerative Disease: A Study on Parkinson Disease, pp. 990-995

Singh, Gurpreet	National Univ. of Singapore
Vadera, Meet	Department of Mechanical Engineering, Indian Inst. of Tech
Samavedham, Lakshminarayanan	National Univ. of Singapore
Lim, Erle Chuen-Hian	Department of Neurology, National Univ. Health System, Nati

A new era of intelligent medical diagnostics is emerging with the development of machine learning-based algorithms to diagnose neurodegenerative diseases (NDDs). In the present work, we discuss an innovative framework that uses principal component analysis (PCA) for feature extraction, Fisher discriminant ratio (FDR) for feature selection and support vector machines (SVM) for classification of Healthy controls, Parkinson's Disease and SWEDD subjects. We have extended our framework to handle the challenge of multi-class disease diagnosis, wherein, accuracy up to 100% has been achieved. This demonstrates the potential of the present methodology to be developed into a clinical relevant diagnostic and decision support system.

10:50-11:10 WeA2.2

Hydrocyclone Cut-Size Estimation Using Artificial Neural Networks, pp. 996-1001

van Loggenberg, Sarita	North-West Univ. Potchefstroom
van Schoor, George	North-West Univ
Uren, Kenneth Richard	North-West Univ
van der Merwe, Frederik	North-West Univ

The hydrocyclone is widely used throughout the mineral processing industry when working with slurries. It is either used for classifying, desliming or dewatering. Hydrocyclones are inexpensive, application-efficient and relatively small to employ. In order to quantify its separation efficiency, models are utilised to estimate the cut-size and sharpness of classification coefficient, usually in the form of a partition curve. Most models are based on experimentally obtained data and are therefore not always universally applicable. Over the last decade researchers have started employing Artificial Neural Networks (ANNs) in order to obtain a dynamic model. This study endeavoured to use experimentally acquired data to develop models that predict the cut-size. The models are discussed and evaluated in detail and the best predicting model was compared to a conventional model from literature.

11:10-11:30 WeA2.3

Parameter Estimation and Model Order Identification of LTI Systems, pp. 1002-1007

Varanasi, Santhosh Kumar	Indian Inst. of Tech. Hyderabad
Jampana, Phanindra	Indian Inst. of Tech. Hyderabad

In this paper, a sparsity seeking optimization method for estimating the parameters along with the order of output error models of single-input and single-output (SISO), linear time invariant (LTI) system is proposed. It is demonstrated with the help of simulations that the proposed algorithm gives accurate parameter and order estimates on a variety of systems.

11:30-11:50 WeA2.4

Identication of Wiener Models in the Presence of ARIMA Process Noise, pp. 1008-1013

Aljamaan, Ibrahim	Univ. of Calgary
Westwick, David	Univ. of Calgary
Foley, Michael	Univ. of Calgary

In this paper, a Prediction Error based algorithm is developed for the identification of a Wiener system, a linear dynamic subsystem followed by a static non-linearity, in the presence of a non-stationary disturbance added before the static non-linearity. This structure represents a non-stationary process disturbance, as is common in chemical process control applications. In the proposed method, the disturbance part is restructured to be stationary by differencing the input signal and implicit differencing of the unmeasured intermediate signal. First, an approximate but linear in the variables model is fitted, and used to construct an initial estimate of a parametric system model. This is then refined using a quasi-Newton optimization. Finally, Monte-Carlo simulation is used demonstrate the performance of the algorithm.

11:50-12:10 WeA2.5

Identification of Linear Dynamic Systems Using Dynamic Iterative Principal Component Analysis, pp. 1014-1019

Maurya, Deepak	Indian Inst. of Tech. Madras
Tangirala, Arun K.	Indian Inst. of Tech. Madras
Narasimhan, Shankar	Indian Inst. of Tech. Madras

The paper is concerned with identifying models from data that have errors in both outputs and inputs, popularly known as the errors-in-variables (EIV) problem. The total least squares formulation of the problem is known to offer a few well-known solutions. In this work, we present a novel and systematic approach to the identification of linear dynamic models for the EIV case in the principal component analysis (PCA) framework. A methodology for the systematic recovery of the process model, including the determination of order and delay, using what we term as dynamic, iterative PCA is presented. The core step consists of determining the structure of the constraint matrix by a systematic exploitation of the stacking and PCA order, input-output partitioning of the constraint matrix and an appropriate rotation. Optimal estimates of the (input-output) noise covariance matrices are also obtained. The proposed method can be applied to a broad class of linear processes including the case of unequal and unknown error variances. Simulation results are presented to demonstrate the effectiveness and consistency of the proposed method.

WeA3	Room T3
Performance and Fault Monitoring III (Regular Session)	
Chair: Hovd, Morten	Norwegian Univ. of Science & Tech. (NTNU)
Co-Chair: Shah, Sirish L.	Univ. of Alberta

10:30-10:50 WeA3.1

An Adaptive Non-Linearity Detection Algorithm for Process Control Loops, pp. 1020-1025

Aftab, Muhammad Faisal	Norwegian Univ. of Science & Tech. (NTNU)
Hovd, Morten	Norwegian Univ. of Science & Tech. (NTNU)
Huang, N	Central Univ
Sivalingam, Selvanathan	Siemens AS

Non-linearities are considered to be a major source of oscillations and poor performance in industrial control systems, as 20-30 % of loops are reported to be oscillating due to valve non-linearities. This fact has led to a significant effort aimed at the detection and diagnosis of non-linearities; in particular for valve non-linearities in the control loops. The current paper presents an adaptive algorithm, based on HHT (Hilbert Huang Transform), for non-linearity detection and isolation in process systems. The HHT is an adaptive data analysis technique that is applicable to non-linear and non-stationary time series. An index termed the {it Degree of Non-Linearity} (DNL), based on intra-wave frequency modulation, is used to identify the presence of non-linearity in the

signal generating system. The proposed method is shown to be more robust in differentiating between linear and non-linear causes of oscillations when compared to existing methods, and can handle non-stationary effects.

10:50-11:10	WeA3.2

Process Discovery of Operator Actions in Response to Univariate Alarms, pp. 1026-1031

Hu, Wenkai	Univ. of Alberta
Al-Dabbagh, Ahmad	Univ. of Alberta
Chen, Tongwen	Univ. of Alberta
Shah, Sirish L.	Univ. of Alberta

To capture the experience of skilled operators in response to alarm notifications, a systematic method of process discovery for operator actions in response to univariate alarms is proposed. The contributions of the paper are two folds. First, the transitions of alarm states are defined and formulated as a Petri net model. Second, the methods of process discovery through Alarm & Event logs are presented, where the logs are segmented and reorganized in a format suitable for processing by process discovery algorithms. Finally, the effectiveness and practicality of the proposed methods are illustrated using an industrial case study.

11:10-11:30	WeA3.3

Mixture Probabilistic PCA for Process Monitoring - Collapsed Variational Bayesian Approach, pp. 1032-1037

Raveendran, Rahul	Univ. of Alberta
Huang, Biao	Univ. of Alberta

Mixture of probabilistic principal component analyzers (MPPCA) has been used for modeling non-Gaussian process data and process monitoring in the past. However, selection of the appropriate cardinality and local dimensionality for MPPCA is a challenging task and remains as a bottleneck. Previously, variational Bayesian expectation maximization (VBEM) learning has been used to solve this issue. However, the lower bound for the log marginal estimated using VBEM can be far off from the true log marginal. To obtain a better lower bound, collapsed variational Bayesian technique with a new collapsing scheme is used in this paper. The capability of MPPCA models learned using the proposed scheme is demonstrated in simulated and industrial process data.

11:30-11:50	WeA3.4

A Revised Technique of Stiction Compensation for Control Valves, pp. 1038-1043

Bacci di Capaci, Riccardo	Univ. of Pisa
Scali, Claudio	Univ. of Pisa
Huang, Biao	Univ. of Alberta

A well-established compensation technique to remove oscillations caused by control valve stiction is the two-moves method. However, the actual versions of this technique present major drawbacks, as the long time for implementation and, mostly, some strong assumptions on the valve position in oscillation. A recent version of two-moves compensation has proven to reduce the time of execution. Nevertheless, this method does not allow the control loop to handle set point tracking and disturbance rejection. The present paper proposes a revised version of two-moves stiction compensation method, which overcomes previous limitations. This new approach is based on the estimation of controller output associated with the desired valve position at the steady-state, by using the amplitude of oscillation before compensation and through the estimate of valve stiction, obtainable with specific techniques. In this case, fast responses are possible as well as a complete removal of the oscillation. In addition, set point tracking and disturbance rejection are guaranteed, by monitoring the control error and by switching temporarily to a standard PI(D) controller. Simulation examples and applications to a pilot plant show the effectiveness of the proposed method.

11:50-12:10	WeA3.5

Concurrent Canonical Correlation Analysis Modeling for Quality-Relevant Monitoring, pp. 1044-1049

Zhu, Qinqin	Univ. of Southern California
Liu, Qiang	Northeastern Univ
Qin, S. Joe	Univ. of Southern California

Canonical correlation analysis (CCA) is a well-known data analysis technique that extracts multidimensional correlation structure between two groups of variables. Due to the advantages of CCA on quality prediction, CCA-based modeling and monitoring are discussed in this paper. To overcome the shortcoming of CCA that focuses on correlation but ignores variance information, a new concurrent CCA (CCCA) modeling method is proposed to completely decompose the input and output spaces into ve subspaces, to retain the CCA efficiency in predicting the output while exploiting the variance structure for process monitoring using subsequent principal component decomposition in the input and output spaces, respectively. The corresponding monitoring statistics and control limits are then developed in these subspaces. The Tennessee Eastman process is used to demonstrate the eeffectiveness of CCCA-based monitoring methods.

WeA4	Room T2

Modeling and Control of Microalgae Processes (Regular Session)

Chair: Bernard, Olivier	INRIA

10:30-10:50	WeA4.1

Parameter Identification of a Dynamic Model of Cultures of Microalgae Scenedesmus Obliquus – an Experimental Study, pp. 1050-1055

Deschenes, Jean-Sebastien	Univ. Du Quebec a Rimouski
Vande Wouwer, Alain	Univ. of Mons

This paper discusses the development of a dynamic model of cultures of microalgae Scenedesmus obliquus in photo-bioreactors. Unknown parameters are estimated from experimental data collected from cultures operated in batch mode as well as with pulses of inlet substrates, and achieved at different incident light intensities. The identification procedure involves the minimization of a weighted-least squares criterion using a multistart strategy and a combination of Nelder-Mead and Levenberg-Marquardt algorithms. The parameter error covariance matrix is estimated using the Fisher Information Matrix, and confidence intervals are provided both for the parameters and the model prediction. The latter is achieved through Monte Carlo simulation based on Latin hypercube sampling. The model validation is quite satisfactory, and the resulting model could be used for model-based control.

10:50-11:10	WeA4.2

Design of a Robust Lipschitz Observer - Application to Monitoring of Culture of Micro-Algae Scenesdesmus Obliquus, pp. 1056-1061

Feudjio, Christian	Univ. of Mons
Deschenes, Jean-Sebastien	Univ. Du Quebec a Rimouski
Bogaerts, Philippe	Univ. Libre De Bruxelles
Vande Wouwer, Alain	Univ. of Mons

In this study, the application of Lipschitz observers to the monitoring of cultures of micro-algae in photo-bioreactors is investigated. To design the observer, the dynamic model has to be structured into an observable linear part and a nonlinear Lipschitz part. A systematic method is proposed for the definition of the linear part, so as to ensure that it is stable and observable. The observer is tested in a real-life application, namely cultures of micro-algae Scenesdesmus obliquus, where the internal quota has to be estimated from either biomass measurements only or biomass and medium substrate concentrations. The Lipschitz observer shows robust performance, as compared to the extended Kalman filter.

11:10-11:30	WeA4.3

Optimal Operation of Algal Ponds Accounting for Future Meteorology, pp. 1062-1067

De Luca, Riccardo — Univ. of Padova
Béchet, Quentin — INRIA
Bezzo, Fabrizio — Univ. of Padova
Bernard, Olivier — INRIA

Biofuel production from microalgae requires optimizing the operation of cultivation systems (i.e. outdoor ponds) for this process to be economically sustainable. Controlling algal ponds is complex as the cultivation system is exposed to fluctuating conditions. The strategy investigated in this study uses weather forecast coupled to a predictive model of algal productivity to optimize pond operation. The selected controlled variables were the rates of fresh medium injection and culture removal into and from the pond. This optimization strategy was applied at two locations in France and was shown to increase the productivity by a factor 1.7-2.4 compared to where the pond depth and dilution rate were kept constant over time. A thorough analysis of the optimizer behavior showed that this increase of productivity was achieved by `flushing' the pond and controlling the pond depth. These mechanisms allowed maintaining the biomass concentration and the pond temperature near their optimal values. The complex behavior of the optimizer was reduced to six simple rules that could be used as guidelines for practical operation.

11:30-11:50 — WeA4.4

The Photoinhibistat: Operating Microalgae Culture under Photoinhibition for Strain Selection, pp. 1068-1073

Mairet, Francis — Inria
Bernard, Olivier — INRIA

Microalgae have recently attracted attention for their potential to produce high added compounds, proteins, and even biofuels. Our paper seeks to develop a control strategy for light-limited continuous culture imposing a stress for which microalgae have to adapt. This operating mode - called photoinhibistat - consists, for a culture with a constant dilution rate, in varying the incident light in order to regulate the light at the bottom of the reactor, inducing a light stress. Based on a simple model of light-limited growth, we analyze the dynamics of the photoinhibistat in monoculture and in competition. It appears that the photoinhibistat can be used to select, from the initial microalgae population, the strain with the highest resistance to photoinhibition.

11:50-12:10 — WeA4.5

A Bacteriostatic Control Approach for Mixotrophic Cultures of Microalgae, pp. 1074-1078

Deschenes, Jean-Sebastien — Univ. Du Quebec a Rimouski

Mixotrophic mode of cultivation is an effective means of producing algal biomass. However, as it involves growth on an organic carbon source, the risks of bacterial contamination (and takeover) are higher at large production scales (e.g. pilot or industrial scale) where adequate sterilization is difficult to ensure. This observation also holds for closed systems such as photobioreactors. A recent study showed that the bacterial population can be contained under particular constraints on the available nutrients in the culture medium. Using very simple models for the dynamic behavior (growth and nutrient consumption) of both species involved (algae and bacteria), this paper investigates biomass productivity aspects under such operational constraints as well as possible approaches for conducting the system.

WeB1 — Room T1

Model Based Control IV (Regular Session)

Chair: Ydstie, B. Erik — Carnegie Mellon Univ
Co-Chair: De Keyser, Robin M.C. — Ghent Univ

13:00-13:20 — WeB1.1

Reference Tracking Using a Non-Cooperative Distributed Model Predictive Control Algorithm, pp. 1079-1084

Maxim, Anca — Tech. Univ. "Gheorghe Asachi" of Iasi
Ionescu, Clara — Ghent Univ
Caruntu, Constantin - Florin — Tech. Univ. "Gheorghe Asachi" of Iasi
Lazar, Corneliu — Tech. Univ. "Gheorghe Asachi" of Iasi
De Keyser, Robin M.C. — Ghent Univ

In this paper, a non-cooperative distributed model predictive control (DMPC)algorithm for tracking constant references is developed and evaluated. As such, an augmented model is employed (i.e. the control loop is embedded with integrators) and the augmented state contains the state increments and the error between the reference and the predicted output. The algorithm is tested in real life experiments on the quadruple tank process with non-minimum phase behaviour. The experimental results show acceptable performance index for the DMPC method when compared with the centralized approach.

13:20-13:40 — WeB1.2

Hybrid Model Based Control for Membrane Filtration Process, pp. 1085-1090

Chan, Lester Lik Teck — Chung-Yuan Christian Univ
Chou, Chen-Pei — Chung-Yuan Christian Univ
Chen, Junghui — Chung-Yuan Christian Univ

Membrane fouling can affect the performance of the membrane-based filtration for water treatment. Fouling thus increases operational costs. This work presents a modeling framework that combine first principle model with Gaussian process model that aims to reduce the energy load affected by the effect of fouling on the system. Based on the expected improvement algorithm, an optimization control is proposed to handle the long duration of the operation to achieve the most economical operation in term of energy load.

13:40-14:00 — WeB1.3

Reaction Variants and Invariants Based Observer and Controller Design for CSTRs, pp. 1091-1096

Zhao, Zixi — Carnegie Mellon Univ
Wassick, John — The Dow Chemical Company
Ferrio, Jeff — The Dow Chemical Company
Ydstie, B. Erik — Carnegie Mellon Univ

This work shows that kinetic information is not needed to estimate states (compositions) and control continuous stirred tank reactors (CSTRs). An asymptotic observer is developed using reaction invariants to provide on-line estimates of unmeasured compositions. The estimates are used in a feedback controller, based on inventory control theory, to control compositions and reactor temperature. The dynamics of the reaction system are reduced using reaction variants and invariants. The reaction rates are estimated through differentiation of reaction variants, such that no kinetic information is required. An example of a serial reaction in a CSTR illustrates the theoretical results and the performance of the proposed adaptive control approach.

14:00-14:20 — WeB1.4

Proactive Actuator Fault-Tolerance in Economic MPC for Nonlinear Process Plants, pp. 1097-1102

Knudsen, Brage Rugstad — Norwegian Univ. of Science & Tech. (NTNU)

This paper presents a scheme for proactive accommodation of incipient actuator faults in nonlinear process plants operated with economic model predictive control (EMPC). The control scheme implements a switching from nominal economic operations to a safe-transition mode when receiving a warning about an incipient fault in one of the actuators, thereby ensuring that the plant is proactively steered to a steady-state point where the suspect control actuator is inactive. Upon reaching this safe steady-state point, the faulty actuator can be safely disconnected and repaired without shutting down the plant, before the controller subsequently resumes nominal economic operation. To steer the plant to the safe steady-state point, we impose an L1 penalty function in order to achieve dead-beat control and reach the steady state in finite time. We provide a lower bound on the penalty parameter to ensure exactness of the penalty function, and analyze stability and convergence properties of the proactive fault-tolerant EMPC scheme. We demonstrate application of the proposed scheme on a non-isothermal continuously stirred tank reactor.

14:20-14:40	WeB1.5

Constrained Multivariable Predictive Control of a Train of Cryogenic 13C Separation Columns, pp. 1103-1108

Ionescu, Clara	Ghent Univ
Muresan, Cristina Ioana	Tech. Univ. of Cluj Napoca
Copot, Dana	Ghent Univ
De Keyser, Robin M.C.	Ghent Univ

This work presents a linear, constrained, multivariable predictive control strategy, i.e. EPSAC (Extended Prediction Self-Adaptive Control) applied to a train of three distillation columns. The columns are used to obtain the carbon isotope 13C used widely in medicine and specific industries. The oversimplified models of the three columns stem from a real-life plant designed and constructed in the National Institute for Research and Development for Isotopic and Molecular Technologies, in Cluj Napoca, Romania. The simulation results suggest the strategy is applicable to this process.

WeB2	Room T2

Modelling and System Identification III (Regular Session)

Chair: McAuley, K.B.	Queen's Univ
Co-Chair: Vande Wouwer, Alain	Univ. De Mons

13:00-13:20	WeB2.1

Bayesian Estimation in Stochastic Differential Equation Models Via Laplace Approximation, pp. 1109-1114

Karimi, Hadiseh	Queen's Univ
McAuley, K.B.	Queen's Univ

A Bayesian algorithm is developed for estimating measurement noise variances, disturbance intensities and model parameters in nonlinear stochastic differential equation (SDE) models of interest to chemical engineers. The proposed Bayesian algorithm uses prior knowledge about parameters and builds on the Laplace Approximation Maximum Likelihood Estimation (LAMLE) algorithm (Karimi and McAuley, 2014). The effectiveness of the proposed algorithm is compared with LAMLE using a nonlinear continuous stirred tank reactor (CSTR) model. Parameter estimation using 2000 simulated datasets reveals that the proposed method provides more precise and less biased estimates, especially for small data sets.

13:20-13:40	WeB2.2

A Generalized Instrumental Variable Method Based on Matrix Decomposition for Simultaneous Identification of Bi-Directional Paths in Closed-Loop Systems, pp. 1115-1120

Jiang, Benben	Beijing Univ. of Chemical Tech
Zhu, Qunxiong	Coll. of Information Science and Tech. Beijing Univ
Zhu, Xiaoxiang	Air Products
Geng, Zhiqiang	Beijing Univ. of Chemical Tech

In this paper, a generalized instrumental variable (GIV) identification method based on a UD factorization is proposed for closed-loop systems with colored noise. The major characteristic of the proposed approach is that all the parameter estimates and the corresponding loss function values for both forward and backward path models with orders possibly from zero to n can be obtained simultaneously after a single step of UD factorization. The identification accuracy properties, in terms of the covariance matrix of the parameter estimates, are investigated and illustrated via simulation examples.

13:40-14:00	WeB2.3

Latent Autoregressive Gaussian Processes Models for Robust System Identification, pp. 1121-1126

Mattos, César L. C.	Federal Univ. of Ceará (UFC)
Damianou, Andreas	Univ. of Sheffield
Barreto, Guilherme A.	Federal Univ. of Ceará (UFC)
Lawrence, Neil D.	Univ. of Sheffield

We introduce GP-RLARX, a novel Gaussian Process (GP) model for robust system identification. Our approach draws inspiration from nonlinear autoregressive modeling with exogenous inputs (NARX) and it encapsulates a novel and powerful structure referred to as latent autoregression. This structure accounts for the feedback of uncertain values during training and provides a natural framework for free simulation prediction. By using a Student-t likelihood, GP-RLARX can be used in scenarios where the estimation data contain non-Gaussian noise in the form of outliers. Further, a variational approximation scheme is developed to jointly optimize all the hyperparameters of the model from available estimation data. We perform experiments with five widely used artificial benchmarking datasets with different levels of outlier contamination and compare GP-RLARX with the standard GP-NARX model and its robust variant, GP-tVB. GP-RLARX is found to outperform the competing models by a relatively wide margin, indicating that our latent autoregressive structure is more suitable for robust system identification.

14:00-14:20	WeB2.4

Modeling, Sensitivity Analysis and Parameter Identification of a Twin Screw Extruder, pp. 1127-1132

Grimard, Jonathan	Univ. De Mons
Dewasme, Laurent	Univ. De Mons
Thiry, Justine	Univ. De Liège
Krier, Fabrice	Univ. De Liège
Evrard, Brigitte	Univ. De Liège
Vande Wouwer, Alain	Univ. De Mons

Following the recent success of hot-melt extrusion in the pharmaceutical field, monitoring and control are increasingly applied. In this study, a mathematical model consisting of mass and energy balance partial differential equations is developed and parameters related to material transportation are inferred from experimental data collected from a pilot plant. This data is relative to the output residence time distribution of active product. Parameter identification is complemented by a parametric sensitivity analysis and the computation of confidence intervals. Direct and cross-validation results demonstrate the good predictive capability of the model, which could probably be exploited for model-based control at a next stage.

14:20-14:40	WeB2.5

Optimal Experimental Design in the Evaluation of Food Packaging Compliance with Safety Regulations, pp. 1133-1138

Mauricio-Iglesias, Miguel	Univ. De Santiago De Compostela

The determination of diffusivity of compounds that can be transferred from packaging into food products is a keystone to ensure consumer's safety. However, no clear guidelines exist as how the diffusion experiment should be designed in order to maximise the accuracy of the estimated parameter. With the perspective of optimal experimental design, a methodology to estimate the diffusivity of a migrating compound in a polymer is presented, both for global methods (that measure the overall concentration) and local methods (that measure the profile of concentration along the polymer thickness). To demonstrate the methodology, real experimental data (transfer of Uvitex OB from linear low-density polyethylene) are used, and the OED based methodology is benchmarked against other heuristics. It is seen that, although the OED methodology outperforms the rest of methodologies when good initial guesses are available, its performance becomes deteriorated when gross over- or underestimations of the true value are made.

WeB3	Room T3

Modeling, Optimization and Control in Biological Waste/water

Treatment (Invited Session)

Chair: Smets, Ilse	KU Leuven, Department of Chemical Engineering, CREaS
Co-Chair: Villez, Kris	Eawag
Organizer: Smets, Ilse	KU Leuven, Department of Chemical Engineering, CREaS
Organizer: Villez, Kris	Eawag

13:00-13:20 WeB3.1

Non-Linear Data Reconciliation for a Partial Nitritation (Sharon) Reactor (I), pp. 1139-1144

Le, Quan	Ghent Univ
Verheijen, Peter J.T.	Delft Univ. of Tech
Mampaey, Kris E.	Ghent Univ
van Loosdrecht, Mark	TU Delft
Volcke, Eveline	Ghent Univ

This work demonstrates the usefulness of non-linear data reconciliation to evaluate available measurements and estimate unmeasured variables for a full-scale partial nitritation (SHARON) reactor for the treatment of wastewater with high ammonium concentrations. Despite the lack of some measured data, the bilinear approach allowed to satisfy the requirements for data reconciliation and gross error detection, leading to a balanced data set and the estimation of unmeasured variables.

13:20-13:40 WeB3.2

On the Use of Shape-Constrained Splines for Biokinetic Process Modeling (I), pp. 1145-1150

Masic, Alma	Eawag
Srinivasan, Sriniketh	EPFL
Billeter, Julien	EPFL
Bonvin, Dominique	EPFL
Villez, Kris	Eawag

Identification of mathematical models is an important task for the design and the optimization of biokinetic processes. Monod or Tessier growth-rate models are often chosen by default, although these models are not able to represent the dynamics of all bacterial growth processes. This imperfect representation then affects the quality of the model prediction. This paper introduces an alternative approach, which is based on constraints such as monotonicity and concavity and the use of shape-constrained spline functions, to describe the substrate affinity with high parametric flexibility. This way, the difficult task of searching through potentially incomplete rate-model libraries can be circumvented. A simulated case study is used to illustrate the superiority of the proposed method to represent non-ideal growth conditions, where neither Monod nor Tessier kinetics offer a good approximation.

13:40-14:00 WeB3.3

Bioflocculation and Activated Sludge Separation: A PLS Case Study (I), pp. 1151-1156

Smets, Ilse	KU Leuven, Department of Chemical Engineering, CREaS
Gins, Geert	KU Leuven
Van De Staey, Glenn	KU Leuven - Department of Chemical Engineering

Sedimentation and filtration are the most common techniques for activated sludge separation in wastewater treatment plants. Using partial least squares (PLS), the influence of bioflocculation related variables on removal effiency was assessed. Small particles and dissolved polysaccharides are deemed detrimental for filtration, while hydrophobic large flocs improve the filtration performance. Settling worsens when filaments are present and improves with the presence of large flocs. The potential of using PLS is demonstrated, although more measurements and samples of a wide diversity would improve the modeling performance. Such models can then pinpoint crucial measurements for bioflocculation monitoring in relation to separation performance in wastewater treatment plants.

14:00-14:20 WeB3.4

Control of Wastewater N2O Emissions by Balancing the Microbial Communities Using a Fuzzy-Logic Approach (I), pp. 1157-1162

Boiocchi, Riccardo	Tech. Univ. of Denmark
Gernaey, Krist	Tech. Univ. of Denmark
Sin, Gurkan	Tech. Univ. of Denmark

In this work, a fuzzy-logic controller for minimization of the nitrous oxide emission from wastewater treatment plants is developed and tested in a simulation environment. The controller is designed in order to maintain a balance between production and consumption of nitrite by AOB and NOB microorganisms respectively. Thus, accumulation of nitrite is prevented and AOB denitrification, the main N2O producer, is drastically slowed down. The controller is designed to adjust the oxygen supply according to a measured parameter which typically indicates the ratio of the activity of NOB over AOB. The controller is tested on a benchmark simulation model describing the production of N2O during both AOB denitrification and HB denitrification. Comparisons between simulation results of open-loop and closed-loop have revealed the potential of the controller to significantly reduce the amount of N2O emitted (approximately 35%). On the other side, this reduction of N2O was accompanied by an increase in the aeration costs. Moreover, a plant performance evaluation under dynamic disturbances shows that the effluent quality is compromised due to higher requirements of organic carbon by denitrifying heterotrophs. The controller can therefore be considered effective for the reduction of N2O production by AOB but would need to be coupled with a secondary control strategy ensuring a complete oxidation of the nitrogen oxides by heterotrophs to have a good effluent quality.

14:20-14:40 WeB3.5

Full-Scale Implementation of an Advanced Control System on a Biological Wastewater Treatment Plant (I), pp. 1163-1168

Mulas, Michela	Aalto Univ. - School of Engineering
CORONA, Francesco	Aalto Univ. School of Science
Sirviö, Jukka	Mipro Oy
Hyvönen, Seppo	Mipro Ltd
Vahala, Riku	Aalto Univ

The implementation of a multivariable control package for the real-time control and supervision of a biological wastewater treatment plant is reported and discussed. The goal is to improve the plant operation in terms of effluent quality and operational costs. A dynamic matrix control algorithm is put into operation for controlling the ammonia concentration at the end the biological reactor in the activated sludge process. The status of the plant instrumentation is continuously monitored by multivariate statistical technology based on moving windows principal component analysis. Results of the first six months of continuous operation show the ability of the designed predictive control in reducing the aeration energy consumption whilst keeping the ammonia concentration in the effluent within the limits.

14:40-15:00 WeB3.6

Dynamic Modelling of an Anaerobic Digester for Wastes at the Territory Level (I), pp. 1169-1174

Adouani, Nouceiba	Univ. De Lorraine
Pons, Marie-Noelle	Univ. De Lorraine
Hreiz, Rainier	Univ. De Lorraine
Pacaud, Stéphane	Univ. De Lorraine

The operation of an anaerobic digestion located on a farm and primarily fed by cattle slurry and manure, has been simulated using the Anaerobic Digestion Model 1. The effect of seasonally varying temperature on the biological reactions has been taken into account, as well as the non-availability of cattle slurry in summer. This can be compensated by co-digesting other substrates easily found in the vicinity of the farm such as glycerol (waste from biodiesel production) or roadside green weed silage.

WeB4	Room T4
Inferential Sensing, State Estimation and Sensor Development II (Regular Session)	

Chair: Swartz, Christopher L.E. — McMaster Univ

Co-Chair: Shardt, Yuri — Univ. of Duisburg-Essen

13:00-13:20 WeB4.1

A Multi-Rate Moving Horizon Estimation Framework for Electric Arc Furnace Operation, pp. 1175-1180

Shyamal, Smriti — McMaster Univ

Swartz, Christopher L.E. — McMaster Univ

Electric arc furnaces (EAFs) are widely used in steel industries to produce molten steel from scrap metal. EAF operation, being a highly energy intensive process, is characterized by a limited number of measurements at multiple rates, most of which do not correspond to system states. The ability to estimate the states would enhance the application of control and real-time optimization strategies. In this work, a multi-rate moving horizon estimation (MHE) framework for EAF operation under flat-bath conditions is introduced and implemented. Key features are the restructuring of the MHE problem to a parameter estimation problem, multi-rate measurement handling, and use of a nonlinear model. The approach is implemented in the gPROMS (General Process Modeling System) modeling language. The components of the framework are presented, and the method is applied to a case study illustrating its performance.

13:20-13:40 WeB4.2

Phase Partition for Nonlinear Batch Process Monitoring, pp. 1181-1186

Liu, Jingxiang — Dalian Univ. of Tech

Liu, Tao — Dalian Univ. of Tech

zhang, jie — Newcastle Univ

A window-based step-wise sequential phase partition method is proposed for monitoring nonlinear batch processes with multiphase operations. The three-dimensional batch data are unfolded in the batch-wise direction to facilitate establishing the kernel principle component analysis (KPCA) models. A moving window is introduced to maintain the kernel parameters unchanged for computation while preserving the time sequence of different phases, thus capable of significantly reducing the storage space of kernel matrices and the computation complexity. A numerical case and a penicillin fermentation process are used to demonstrate the effectiveness and merit of the proposed method.

13:40-14:00 WeB4.3

Comparative Study of Multicomponent Distillation Static Estimators Based on Industrial and Rigorous Model Datasets, pp. 1187-1192

Torgashov, Andrei — FEB RAS

Skogestad, Sigurd — Norwegian Univ. of Science & Tech. (NTNU)

Kozlov, Alexey — Gazpromneft-Omsk Refinery

The comparative study of static estimators (soft sensors) for multicomponent distillation process based on the industrial and calibrated rigorous model datasets is considered. The sequence of distillation columns of FFC unit is analyzed as industrial case study. The contribution of the paper is to develop a method aimed to incorporate a priori knowledge about process in terms of rigorous models for static estimator design when the training sample is small and contains measurement errors. The superiority of constrained optimization approach for SE design over conventional robust M-estimator is reported. The system of constraints is derived from calibrated rigorous model of industrial plant.

14:00-14:20 WeB4.4

Development of Soft Sensors for the Case Where the Time Delay Is Random, pp. 1193-1198

Shardt, Yuri — Univ. of Duisburg-Essen

Yang, Xu — Univ. of Science and Tech. Beijing

Time delay and sampling rate are two conditions that can make the design and implementation of soft sensors difficult due limiting the amount of information that can be obtained about the true process. Another wrinkle is the fact that neither of these two parameters are necessarily constant, with the value changing due to changes in the process. One such area of concern is the hot steel mill rolling process, where variable time delay can lead to problems with controlling the process. This paper seeks to examine the appropriate design of the bias update term of the soft sensor in light of variable, but known, time delays for a process operating with constant sampling rate and for both open- and closed-loop conditions. Using a mathematical approach to the problem, the previous results are extended to consider such a case. It is shown that if the process has variable time delay, then designing the bias update term in the soft sensor is very important, as it can have implications for process stability and trackability. Simulations are included to show the impact of different bias update terms.

14:20-14:40 WeB4.5

Robust Observation Strategy to Estimate Unknown Inputs, pp. 1199-1204

Torres, Ixbalank — Univ. De Guanajuato

Vargas, Alejandro — Inst. De Ingenieria UNAM

Buitron, German — Inst. De Ingenieria UNAM

This article presents a robust estimation strategy to reconstruct unknown inputs for nonlinear systems. The observer proposed consists of a Luenberger observer, which estimates the internal states of the system, coupled to a super-twisting observer, which reconstructs the unknown input considering the precedent estimations. The feasibility of the strategy is demonstrated for a real biohydrogen production process.

14:40-15:00 WeB4.6

On-Line Estimation of the Reactions Rates from Sampled Measurements in Bioreactors, pp. 1205-1210

Bouraoui, Ibtissem — GREYC

Farza, Mondher — Univ. De Caen, ENSICAEN

Ménard, Tomas — Univ. De Caen

Ben Abdennour, Ridha — Enig, Conpri

M'Saad, Mohammed — GREYC

Simple high gain observer-based estimators which allow the estimation of the reaction rates from the measurements of component concentrations inside bioreactors are presented. The main properties of these estimators lie in the fact that the measurements of the component concentrations are non available in a continuous manner, as generally assumed in most available algorithms, but only at sampling instants. The proposed estimators, called continuous-discrete observer, result from the design of available estimators which assume the availability of the measurements in a continuous manner. It is shown that for relatively small values for the sampling periods, which may be time-varying, the proposed continuous-discrete observers inherit the same performance as the purely continuous observers in terms of the accuracy of estimation and sensitivity to noise measurements. Simulations results dealing with typical bioreactor example are given in order to illustrate the performance and the main properties of the proposed estimators.

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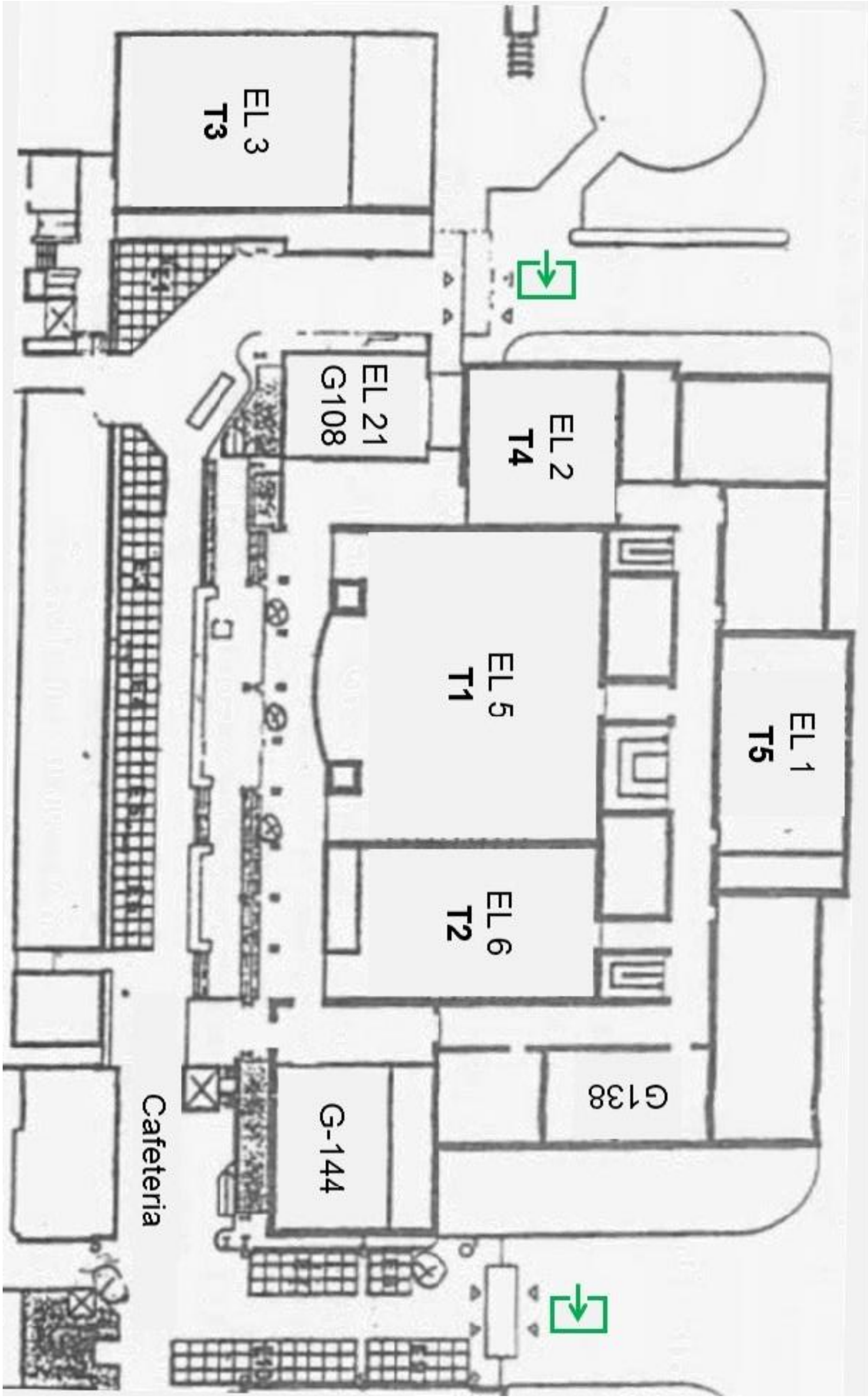

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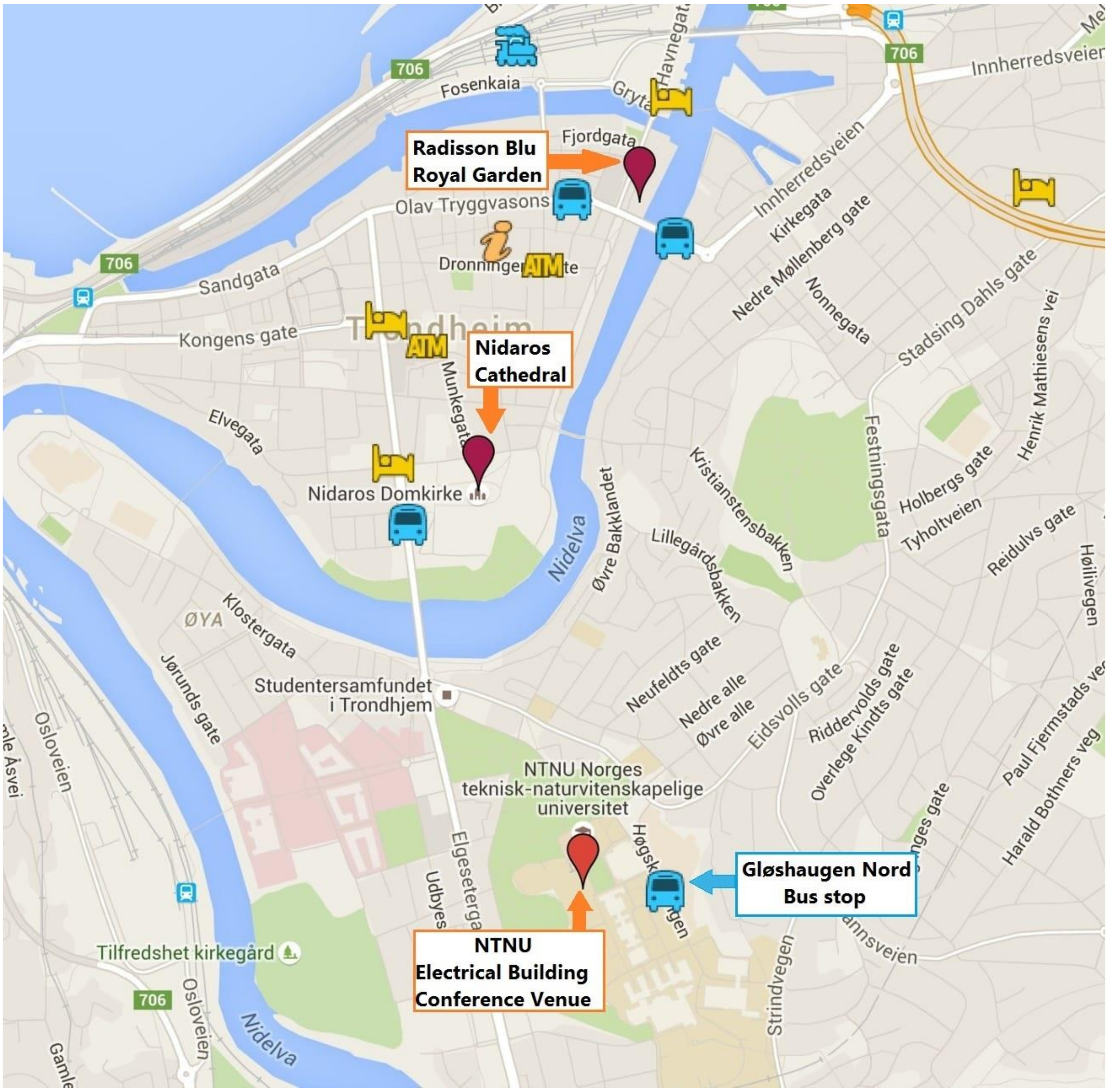

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