34^{th} Benelux Meeting

on

Systems and Control

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Conference Booklet

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Book of Abstracts 34^{th} Benelux Meeting on Systems and Control

KU Leuven - Departement Werktuigkunde
Celestijnenlaan 300B, B-3001 Heverlee (Belgium)

Program Overview

Tuesday March 24, 2014

11:25 – 11:30	P0 Les Arcades *Welcome and Opening*			
11:30 – 12:30	P1 Les Arcades *PID: Past, present and perspectives* Tore Hägglund			
12:30 – 14:00	Lunch			
Room	Les Arcades *Optimization I*	Emanuel *Mechanical Engineering I*	Impressario *Identification I*	Bloemen *Model Reduction*
14:00 – 14:25	Taylor	Romdlony	Verbeke	Jongsma
14:25 – 14:50	Huang	Chevalier	Darwish	Verkerk
14:50 – 15:15	Trefois	Trip	Hollander	Schaub
15:15 – 15:40	Iutzeler	Couto	Weerts	Giovannini
15:40 – 16:05	Telsang	Kapitaniuk	Noël	van Mourik
16:05 – 16:30	Break			
Room	Les Arcades *Games & Agents I*	Emanuel *Biochemical Engineering*	Impressario *Identification II*	Bloemen *Control I*
16:30 – 16:55	Senejohnny	Richelle	Csurcsia	Doban
16:55 – 17:20	Gueuning	Fernandes	Voorhoeve	Proskurnikov
17:20 – 17:45	Su	Gziri	Vaes	Biemond
17:45 – 18:10	Gonze	Nimmegeers	Nguyen	Borgers
18:10 – 18:35	Riehl	Taghvafard	Boussé	Bobiti
18:35 – 19:00	Les Arcades *Meet the Experts: Session I* Tore Hägglund, Achim Kienle, Jaqueline Scherpen, Robain De Keyser, Julien Hendrickx, Pierre-Antoine Absil, Rik Pintelon, Johan Schoukens, Maarten Steinbuch			
19:00 – 21:00	Dinner			

Wednesday March 25, 2014

Room	Les Arcades *Optimization II*	Emanuel *MPC*	Impressario *Identification III*	Bloemen *Systems Theory I*	Seaside *Control Applications I*
09:00 – 09:25	Hollanders	Bachnas	Guerra	Van Eeghem	Alkano
09:25 – 09:50	Gerencsér	Rostampour	De Cock	Markovsky	Siraj
09:50 – 10:15	Feng	Nguyen	Van Loock	Debals	Van Parys
10:15 – 10:40	Van Willigenburg	Wang	Scholten	Potters	Yanami
10:40 – 11:05	Mehrkanoon	Hanema	Esfahani	Potters	Fernandes
11:30 – 12:30	P2 Les Arcades *Dynamics and control of particulate processes* Achim Kienle				
12:30 – 14:00	Lunch				
Room	Les Arcades *Control over Networks*	Emanuel *Optimal Control*	Impressario *Identification IV*	Bloemen *Identification V*	Seaside *Control Applications II*
14:00 – 14:25	Haesaert	Verbandt	Merks	Geerardyn	van Beveren
14:25 – 14:50	Romijn	Stoev	Bronders	Relan	Alavi
14:50 – 15:15	Saltik	Rijnen	Blanken	Gaasbeek	van Duijkeren
15:15 – 15:40	van Horssen	Mercy	Birpoutsoukis	Maes	Debrouwere
15:40 – 16:05	Khashooei	Nicotra	Stoev	Cooman	Megawati
16:05 – 16:30	Break				
Room	Les Arcades *Games & Agents II*	Emanuel *Mechanical Engineering II*	Impressario *Identification VI*	Bloemen *LPV*	Seaside *Nonlinear Control*
16:30 – 16:55	Koerts	Blanken	Habets	Goos	van der Maas
16:55 – 17:20	Vande Kerckhove	Mac Thi	Van Nechel	Schorsch	Monshizadeh
17:20 – 17:45	Ramazi	Beerens	Insuasty	Cox	Fu
17:45 – 18:10	Rossi	Beijen	Zyari	Turk	Barradas-Berglind
18:10 – 18:35	Smyth	van Zundert	Grimard	Lazov	Weitenberg
18:35 – 19:00	Les Arcades *Meet the Experts: Session II* Tore Hägglund, Achim Kienle, Paul Van den Hof, Michel Kinnaert, Julien Hendrickx, Paul Van Dooren, Pierre-Antoine Absil, Rik Pintelon, Johan Schoukens, Maarten Steinbuch				
19:00 – 21:00	Dinner				

Thursday March 26, 2014

Room	Les Arcades *Games & Agents III*	Emanuel *ILC & Adaptive Control*	Impressario *Identification VII*	Bloemen *Systems Theory II*	Seaside *Control II*
09:00 – 09:25	Wei	Tong Duy	Tiels	Vandermeersch	Pilbauer
09:25 – 09:50	Acciani	Yuan	Cahyono	Verhelst	Dehaye
09:50 – 10:15	Engwerda	Chen	Marconato	van der Woude	Wuyts
10:15 – 10:40	Chevalier	Moten	Copot	Philippe	Dolk
10:40 – 11:05	Garcia de Marina	Luo	Huang	Everts	Hao
11:30 – 12:30	P3 Les Arcades *System identification in dynamic networks* Paul M.J. Van den Hof				
12:30 – 14:00	Lunch				
14:00 – 14:20	Les Arcades *DISC Award Ceremony*				
14:20 – 14:55	Les Arcades *Best Junior Presentation Award*				

Short Abstracts

Plenary: P1 **Les Arcades**

PID: Past, present and perspectives
Tore Hägglund

Chair: Clara Ionescu **Tuesday, 11.30–12.30**

Except for the on/off controller, the PID controller is the simplest controller one can imagine. It is also by far the most common controller in industry. The presentation will start with a discussion about the function of the PID controller, how it has been developed over the years, and how it is used in industry today.
The focus of the presentation will be on PID controller tuning. There are numerous methods to tune the parameters of the controller proposed and published in the literature. In spite of this, most PID controllers are badly tuned or even not tuned at all.
There are several aspects that should be taken into account when tuning a PID controller. The closed-loop system should behave well with respect to setpoint changes, load disturbances, and measurement noise. It must also be robust to process variations, since most processes are nonlinear. Very few design methods take all these aspects into account, especially not simple ones. The many aspects and the fact that the specifications vary from case to case make the PID controller tuning a trade-off problem, that can be seen as a constrained optimization problem. The trade-off trade-off has to be made by the engineers, either manually or computer based.
Measurement noise has only recently been taken into account in PID controller tuning. This may be one reason why the derivative part is so seldom used in practice. It is difficult to take the noise into account without knowledge of the noise characteristics, but it is suggested that the filter in the PID controller is tuned so that it is as effective as possible in reducing the control signal variations due to noise, but with a limited reduction of the control performance at load disturbances.
Finally, it should be remarked that even a good design method will not solve the problem that the engineers have very limited time to spend on the controller tuning. Therefore, the presentation ends with a discussion about automatic tuning procedures, and how these should be developed to meet the demands and be accepted and used more extensively in industry.

TuP01 **Les Arcades**

Optimization I

Chair: Julien Hendrickx **Tuesday, 14.00–16.05**

TuP01-1 **14.00–14.25**

First-order Methods for Convex Optimization through Smooth Convex Interpolation

Adrien B. Taylor Université catholique de Louvain
François Glineur Université catholique de Louvain
Julien M. Hendrickx Université catholique de Louvain

We have developed a method allowing to build smooth (possibly strongly) convex interpolating functions from a set of points with their corresponding (sub)gradients and function values. We use this procedure on two different applications from the convex optimization framework. The first application is concerned with the recovery of the exact worst-case behaviour of fixed-step first-order methods. The second application is the development of a new bundle-like optimization method.

TuP01-2 **14.25–14.50**

Solving PhaseLift by low-rank Riemannian optimization methods for complex semidefinite constraints

Wen Huang Université catholique de Louvain
Kyle A. Gallivan FSU Florida
Xiangxiong Zhang Purdue University

A framework, PhaseLift, was recently proposed to solve the phase retrieval problem. In this framework, the problem is solved by optimizing a cost function over the set of complex Hermitian positive semidefinite matrices. This approach to phase retrieval motivates a more general consideration of optimizing cost functions on semidefinite Hermitian matrices where the desired minimizers are known to have low rank. This paper considers an approach based on an alternative cost function defined on a union of appropriate manifolds. It is related to the original cost function in a manner that preserves the ability to find a global minimizer and is significantly more efficient computationally. A rank-based optimality condition for stationary points is given and optimization algorithms based on state-of-the-art Riemannian optimization and dynamically reducing rank are proposed. Empirical evaluations are performed using

the PhaseLift problem. The new approach is shown to be an effective method of phase retrieval with computational efficiency increased substantially compared to the algorithm used in original PhaseLift paper.

TuP01-3 **14.50–15.15**

Solving SDD linear systems in nearly-linear time

Maguy Trefois Université catholique de Louvain
Jean-Charles Delvenne Université catholique de Louvain
Paul Van Dooren Université catholique de Louvain

Symmetric and diagonally-dominant (SDD) linear systems appear in many applications of computer science. These systems are usually of important size and solving them is the main computational task. Direct methods for solving linear systems are much too slow in the case of huge systems. In this talk, we present an algorithm for solving SDD systems in time which is nearly-linear in the number of nonzero entries.

TuP01-4 **15.15–15.40**

Online relaxation method for improving linear convergence rates of the ADMM

Franck Iutzeler Université catholique de Louvain
Julien M. Hendrickx Université catholique de Louvain

The Alternating Direction Method of Multipliers (ADMM) is a celebrated technique for performing optimization in a variety of situations ranging from Distributed Optimization to Learning. Relaxation is a well-known optimization technique that enables to improve convergence rates by performing a damping of the algorithm variables. However, finding the optimal choice for the relaxation parameter is in general prohibitive. Our contribution is to perform a convergence rate analysis on a class of linearly converging algorithms and derive a simple online relaxation method that improves these rates. Numerical illustrations on the ADMM confirm our claims.

TuP01-5 **15.40–16.05**

A New Perspective of Percentage Calculation

Bhagyashri Telsang TU Delft

Percentage is an elemental tool in our daily life; it helps us compare different quantities which would otherwise be difficult to compare directly. The usage of percentages is extremely wide; it is used in every application from representing demographic data to indicating oxygen levels in the blood. This paper merely attempts to demonstrate an alternate approach to calculating percentages which are specific to the practical situations in which they are used. The two modifications that this paper takes up are : Size of the sample space (i.e., value of the denominator quantity in the current formula for Percentage calculation) and Quality of the sample space. The new formula that is proposed in the paper addresses these two issues and gives a subjective insight into percentage calculation.

TuP02 **Emanuel**

Mechanical Engineering I

Chair: Robain De Keyser **Tuesday, 14.00–16.05**

TuP02-1 **14.00–14.25**

On the Construction of Control Lyapunov-Barrier Function

Muhammad Zakiyullah Romdlony Rijksuniversiteit Groningen
Bayu Jayawardhana Rijksuniversiteit Groningen

We propose a novel nonlinear control method for solving the problem of stabilization with guaranteed safety. The design is based on the merging of the Control Lyapunov Function (CLF) and Control Barrier Function (CBF). The proposed control method allows us to combine the design of a stabilizing feedback law based on a CLF and the design of safety control based on a CBF(s); both of which can be designed independently.

TuP02-2 **14.25–14.50**

Control of knee joint motion in a dynamic knee rig

Amélie Chevalier Ghent University
Clara M. Ionescu Ghent University
Robin De Keyser Ghent University

The biomechanics of the knee joint have been a focus of extensive research during the past decades. Total knee replacement is a common used treatment for knee injuries. To test the performance of newly designed prostheses, the orthopedic surgeons can use a knee rig where natural movements are imposed on the prosthesis. Controlling the motions and forces applied is the focus of this research by designing a control strategy for this application.

TuP02-3 **14.50–15.15**

An internal model approach to frequency regulation in power grids

Sebastian Trip Rijksuniversiteit Groningen
Mathias Bürger Robert Bosch GmbH
Claudio De Persis Rijksuniversiteit Groningen

We regard the power grid as an interconnected network of different control areas. In order to guarantee reliable operation the frequency is regulated around its nominal value, e.g. 50 Hz. Automatic regulation of the frequency in power grid is traditionally achieved by primary proportional control (droop-control) and a secondary PI-control on the generators, where economic considerations are largely neglected. In our work we formulate the problem within the framework of output agreement on networks. By doing so we are able to regulate the frequency in the presence of unknown and time-varying demands and we can apply the design, based on passivity properties of the system, in a natural way to higher order models including e.g. voltage dynamics. By coordinating the different controllers utilizing communication links we can furthermore realize the minimization of generation costs.

TuP02-4 **15.15–15.40**

Management System for Paintable Batteries

Luis D. Couto Université Libre de Bruxelles
Julien Schorsch Université Libre de Bruxelles
Michel Kinnaert Université Libre de Bruxelles

The reported work aims at developing a battery-management system (BMS) for paintable batteries, a new type of lithium-ion batteries under development. The focus of the presentation lies in the electrochemical model formulation. The general structure of the model made of a set of partial differential equations (PDEs) will be described, and some challenges to be faced regarding parameter estimation will be pointed out.

TuP02-5 **15.40–16.05**

Geometric path following control in a moving frame

Iurii Kapitaniuk Rijksuniversiteit Groningen

The design of guidance laws for the unmanned vehicles is an important problem for the researchers in the field of motion control. One of the most interesting task is the moving path following control. In this case the desired path is attached to a movable frame. This is a natural extension of the classical approaches for stationary frames. An application example of this task is the following by UAV of a moving ground vehicles. In this work I would like to demonstrate the method of solution the similar tasks using the geometric path following framework based on the stabilization of sets. Desired path of movement in the space is represented by an intersection of two implicit surfaces which are defined in the external movable frame. Path following control problem is posed as a problem of maintaining the holonomic relationships between the system outputs. Control is synthesized using the differential geometrical method through nonlinear transformation of initial dynamic model. For this work was selected the simplest model of the fully actuated rigid body to illustrate the main idea of the proposed approach, but the the method can be extended to more complex model trivially.

TuP03 **Impresario**

Identification I

Chair: Roland Tóth **Tuesday, 14.00–16.05**

TuP03-1 **14.00–14.25**

The local polynomial method applied to a lightly damped mechanical MIMO system

Dieter Verbeke Vrije Universiteit Brussel
Egon Geerardeyn Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel

The local polynomial method for estimation of the frequency response matrix will be applied to a lightly damped

mechanical MIMO system. The local polynomial methods result in a non-parametrical suppression of the noise and system transients (leakage errors) in the frequency response matrix and noise (co-)variance estimates. For lightly damped systems they can either significantly reduce the measurement time or, for a given experiment duration, significantly increase the frequency resolution of the frequency response matrix estimate. Although the objective is to apply the methodology to an experimental set-up, namely an active vibration isolation system, the discussion here is limited to a series of simulations dealing with critical features.

TuP03-2 **14.25–14.50**

Selecting Shaping Kernels in Bayesian Identification of LTI Systems: An Orthonormal Basis Functions Approach

M.A.H.Darwish TU Eindhoven
R.Tóth TU Eindhoven
P.M.J. Van den Hof TU Eindhoven

Bayesian system identification has received a serious attention recently. It has been shown that it corresponds to a particular regularisation approach that achieves favourable bias/variance trade-off compared to regular Prediction Error Methods (PEMs). In the regularisation, a so-called kernel function plays an important role by encoding our prior knowledge about the system under study. For example, in case of identification of stable systems, encoding by this kernel an expected decay of the impulse response is crucial for high quality model estimates. In this work, we propose to use Orthonormal Basis Functions (OBFs) as generators of such kernels. A wide range of dynamic properties of impulse responses can be easily included in these kernels via the poles of the OBFs. The basis poles are tuned by marginal likelihood maximisation, which ensures optimality of the resulting estimation approach in the stochastic sense.

TuP03-3 **14.50–15.15**

Decoupling noisy multivariate polynomials in nonlinear system identification

Gabriel Hollander Vrije Universiteit Brussel
Philippe Dreesen Vrije Universiteit Brussel
Mariya Ishteva Vrije Universiteit Brussel
Johan Schoukens

In the field of system identification, the last few decades have witnessed a shift from linear to nonlinear system identification. One special type of nonlinear models are the so-called block-oriented models, and more specifically the Wiener-Hammerstein models. When identifying parallel Wiener-Hammerstein systems based on measurements, a noisy coupled multiple input-multiple output polynomial should be decoupled. However, this decoupling problem has solely been studied for the noiseless case, and not yet for the more involved noisy case. By using the covariance matrix of the polynomial coefficients, we have developed a first step towards the decoupling of noisy multivariate polynomials. This overview describes our contribution to the existing algorithm in the noisy case. For small noise levels (up to 10% of the output level), the covariance matrix method gives a reduction in error up to 10 dB between model and simulation. We expect better results after solving a remaining problem in the covariance matrix algorithm.

TuP03-4 **15.15–15.40**

System identification in dynamic networks

Harm H.M. Weerts TU Eindhoven
Paul M.J. Van den Hof TU Eindhoven
Arne G. Dankers University of Calgary

Interest in black-box modeling of complex dynamic networks is increasing, one particular interesting problem is detecting the network topology. We adopt a flexible network framework and make no a-priori assumptions on uncorrelatedness of noises, sequentially a flexible network model structure is defined without assuming knowledge of the network topology. Due to the flexibility the model set contains infinite models that can represent the network equally well, which is classified as an identifiability problem. Restrictions on the model structure must be made to obtain an identifiable model structure, among many possible choices choosing a diagonal noise model would result in an identifiable model structure. Detecting topology using these network model structures can be done by applying regularization techniques to the identification criterion. Regularized estimates are sparse and are seen as an estimation of the network topology.

TuP03-5 **15.40–16.05**

A comparison of grey-box and black-box approaches in nonlinear state-space modelling and identification

Jean-Philippe Noël Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel
Gaetan Kerschen Université de Liège

In the present contribution, it is shown that, in the case of mechanical systems where nonlinearities are physically localised, the general structure of black-box nonlinear state-space models can be drastically simplified. A more parsimonious, grey-box state-space representation is derived, which is found to be compatible with Newton's second law of dynamics. For demonstration purposes, black-box and grey-box state-space models of the Silverbox benchmark, i.e. an electrical mimicry of a single-degree-of-freedom mechanical system with cubic nonlinearity, are identified using a maximum likelihood estimator. It is found that the grey-box approach allows to reduce markedly modelling errors with respect to a black-box model with a comparable number of parameters. It is also suggested that the greater accuracy of the grey-box model lends itself to the computation of reliable confidence bounds on the model parameters.

TuP04 Model Reduction Bloemen

Chair: Geert Gins **Tuesday, 14.00–16.05**

TuP04-1 **14.00–14.25**

Model Reduction of Networked Systems

H.J. Jongsma Rijksuniversiteit Groningen
H.L. Trentelman Rijksuniversiteit Groningen
M.K. Camlibel Rijksuniversiteit Groningen

Direct application of existing model reduction techniques to networked systems often destroy the spatial structure of the network. In this abstract we investigate clustering based model reduction techniques for leader-follower based multi-agent systems. These techniques preserve some of the network topology and consensus properties of the original system. An a priori upper bound on the modelling error is given.

TuP04-2 **14.25–14.50**

Reducing truncation errors by low order augmentation of the observer model for flexible systems

Koen Verkerk TU Eindhoven

The performance of observers is directly coupled to the accuracy of the observer model. For flexible systems in modal form the system can easily be truncated to contain the dynamics of interest. The discarded modes do however affect the system output at low frequencies. A method is presented to reduce model errors in the frequency region of interest by taking the compliance of discarded modes into account.

TuP04-3 **14.50–15.15**

A linear systems perspective for clustering of complex networks

Michael T. Schaub Université catholique de Louvain & UNamur
Jean-Charles Delvenne Université catholique de Louvain
Renaud Lambiotte UNamur
Mauricio Barahona

We develop a dynamical perspective on community detection based on assessing the time-evolution of a linear time invariant system, as exemplified by a consensus dynamics, taking place on the network. We show how by comparing the transient responses of the system to localized impulses applied at the nodes, we can effectively decompose the system into groups of nodes which dynamically affect the system in a similar way. Interestingly, this dynamical viewpoint can be shown to generalize a number of community detection algorithms proposed in the literature. Notably, Modularity and spectral clustering arise as special cases of this formalism for a particular time. We can thus give an interpretation of these methods in terms of consensus, or its dual random walk process. While diffusion based approaches on network clustering have already received some attention in the literature, our generic linear systems perspective provides an increased flexibility for the construction of specific quality functions for network clustering as it can be constructed from any (marginally) stable linear dynamics and can thus be adapted to the specific problem under investigation.In particular, we highlight how using a consensus-like linear dynamics enables us to naturally define a dynamical network clustering measure for signed graphs, containing both positive and negative edge-weights.

TuP04-4 **15.15–15.40**

ADM1 Model Reduction and Parameter Estimation

Giannina Giovannini UMons
Mihaela Sbarciog UMons
Gonzalo Ruiz-Filippi PUCV Valparaiso
Alain Vande Wouwer

A simple model for anaerobic digestion (AD) is developed using model reduction techniques and weighted-least square identification. The model is generated using data from the ADM1 model as experimental data. The data is analysed using the Maximum Likelihood Principal Component Analysis (MLPCA) to first obtain the minimum number of reactions that can represent this data and to get an estimate of the stoichiometric parameters. Then, maximum likelihood method method for identification is used to estimate the kinetic and re-estimate the stoichiometric parameters. The proposed model includes variables widely available in waste treatment plants, especially; it includes the hydrogen gas concentration as a key variable, which can give important information about the stability of the reactor in a fast and effective way.

TuP04-5 **15.40–16.05**

Model reduction for greenhouse climate control

Simon van Mourik Wageningen UR
Irineo Lopez-Cruz Chapingo University
Peter van Beveren Wageningen UR
Eldert van Henten

We investigated the opportunities of model reduction for greenhouse climate control by comparing a dynamic non-linear mechanistic model against a severely reduced static linear regression model, in order to predict temperature, humidity, and carbon-dioxide concentration as a function of 16 variables related to outdoor climate and control actions.

TuE01 **Les Arcades**

Games & Agents I

Chair: Jean-Charles Delvenne **Tuesday, 16.30–18.35**

TuE01-1 **16.30–16.55**

Denial of Service in Distributed Control and Communication Systems

Danial Senejohnny Rijksuniversiteit Groningen
Pietro Tesi Rijksuniversiteit Groningen
Claudio De Persis Rijksuniversiteit Groningen

Recent years have witnessed a growing interest towards cyber-physical systems (CPSs), i.e. systems with a tight conjoining of computational and physical resources. Their field of application is immense, ranging from autonomous vehicles and supply chains to power and transportation networks. Many of these applications are safety-critical. In CPSs, attacks can in fact cause disruptions that transcend the cyber realm and affect the physical world. For instance, if a critical process is open-loop unstable, failures in the plant-controller communication network can result in environmental damages. In a networked control system, malicious attacks to the communication links can be classified as either false data injection attacks or denial-of-service (DoS) attacks. The former affects the integrity of data by manipulating the packets transmitted over the network, while the latter affects the availability of data by causing packet losses. This work is concerned with DoS attacks in networked control systems. Specifically, we consider a consensus-like control network, in which the communication medium is vulnerable to attack; the attacker objective is to prevent consensus by denying communication among the agents. By introducing the notion of Persistence of Communication (PoC), we provide an explicit characterization of the frequency and duration of DoS attacks under which consensus can be preserved. An example is finally provided to substantiate the analysis.

TuE01-2 **16.55–17.20**

Diffusion Efficiency on temporal networks

Martin Gueuning UNamur & Université catholique de Louvain
Renaud Lambiotte UNamur
Jean-Charles Delvenne Université catholique de Louvain

In this work, we are looking at a diffusion process on a network of agents where the probability of success depends on the allocated time for the attempt. We consider different time-allocation strategies for the agents consisting in a trade-off between many unlikely attempts versus few likely ones. Our model incorporates a bursty behaviour as observed in human-related networks such as Twitter or mailbox checking or face-to-face contact patterns. Our results show that, for the same mean time between two successful transmissions, the former strategy is more efficient in terms of diffusion. This applies to marketing strategies as well as to the study of infectious diseases.

TuE01-3 **17.20–17.45**

Game-theoretic approach for optimal contract design in railway networks

Zhou Su TU Delft
Bart De Schutter TU Delft
Simone Baldi TU Delft

Since the privatization of Dutch railways, the maintenance of the railway infrastructure is performed by private contractors, whose short-term objective are not always fully aligned with the long-term objective of the infrastructure manager, ProRail, and conflicts arise from such misalignment of interests. The principal-agent model from the field of game theory, considers situations with conflicting objectives and asymmetric information, which is suitable to investigate the current performance-based maintenance contract between ProRail and the contractors. A game-theoretic formulation for this real world problem is presented, and the overall aim of this work is to develop new methodologies for optimal contract design that can be applied to situations similar to the maintenance to Dutch railways, i.e. large infrastructure networks like road and water networks.

TuE01-4 **17.45–18.10**

New approaches of Černý's Conjecture

François Gonze Université catholique de Louvain
Raphaël M. Jungers Université catholique de Louvain

We push further a recently proposed approach for studying synchronizing automata and Černý's conjecture, namely, the synchronizing probability function. In this approach, the synchronizing phenomenon is reinterpreted as a Two-Player game, in which the optimal strategies of the players can be obtained through a Linear Program. Our analysis focuses on the concept of triple rendezvous time, the length of the shortest word mapping three states onto a single one. It represents an intermediate step in the synchronizing process, and is a good proxy of its overall length. Using the synchronizing probability function, we obtain a new upper bound on the triple rendezvous time.

TuE01-5 **18.10–18.35**

A Centrality-Based Security Game for Multi-Hop Networks

James Riehl Rijksuniversiteit Groningen
Ming Cao Rijksuniversiteit Groningen

We present a new topological analysis of multi-hop network security in the form of a game played between an attacker who tries to disrupt a network by disabling one or more nodes, and the nodes of the network who must allocate limited resources in defense of the network. After formulating the network security problem as a two-player zero-sum game using node centrality measures, we introduce a fast algorithm to compute Nash equilibrium strategies for the attacker and defender and discuss ongoing work toward distributed solutions.

TuE02 **Emanuel**

Biochemical Engineering

Chair: Anne Richelle **Tuesday, 16.30–18.35**

TuE02-1 **16.30–16.55**

Off-line optimization of baker's yeast production process

Anne Richelle Université Libre de Bruxelles
Philippe Bogaerts Université Libre de Bruxelles

In this study, a macroscopic model (Richelle et al., 2014) was used for the determination of optimal feeding time profiles in carbon and nitrogen sources for a fed-batch bakers yeast production process in the sense of a production criterion. To this end, two different approaches were used and compared with numerical and experimental data: a control vector parameterization approach with mesh refinement and an approach based on the mathematical analysis of optimal operating policy (semi-analytical approach).

TuE02-2 **16.55–17.20**

Metabolic flux analysis using a convex analysis approach

Sofia Fernandes UMons
Georges Bastin Université catholique de Louvain
Alain Vande Wouwer UMons

Metabolic flux analysis (MFA) has been a subject of intense research for almost two decades. It is a useful tool to estimate in vivo metabolic fluxes in, among others, mammalian cell cultures. In this study, a metabolic network with 72 biochemical reactions and m=45 internal metabolites is considered and MFA is applied in order to determine the intracellular fluxes. Due to an insufficient number of extracellular measurements, the classical pseudo-steady state assumption (no accumulation of internal metabolites) leads to an underdetermined system of algebraic equations and a unique solution cannot be computed. To overcome this problem, a convex analysis approach can be used, which provides a way to calculate a set of admissible positive bounds. Our study is based on sets of experimental data from hybridoma HB58 cell batch/perfusion cultures, and the main goal is to investigate the influence of the batch and perfusion operating modes on the metabolic flux intervals.

TuE02-3 **17.20–17.45**

Mathematical modelling of overflow metabolism in hybridoma cell cultures by Flux Balance Analysis

Khadija Mhallem Gziri Université Libre de Bruxelles
Anne Richelle Université Libre de Bruxelles
Philippe Bogaerts Université Libre de Bruxelles

To legitimate overflow metabolism modelling in hybridoma cell cultures, a Flux Balance Analysis (FBA) model is developed. It is based on the assumption that the cells behave so as to maximize biomass growth. Based on a limited number of reactions and measurements, and using three linear constraints, the resulting intracellular fluxes are in agreement with the overflow metabolism.

TuE02-4 **17.45–18.10**

Dynamic metabolic flux analysis in metabolic networks: a non-linear dynamic optimization approach

Philippe Nimmegeers KU Leuven
Filip Logist KU Leuven
Jan Van Impe KU Leuven
Dominique Vercammen

Micro-organisms play an important role in industry, e.g. in food industry and industrial biotechnology. A good insight in the biochemical reactions inside micro-organisms enables model based monitoring, control and optimization of bioprocesses. An important modeling tool in systems biology are metabolic reaction networks in which the knots represent the metabolites (chemical substances produced/consumed in the micro-organisms) and the connections indicate the reaction fluxes between those metabolites. In literature the analysis of metabolic fluxes in steady state conditions is well known. However, to study transient phenomena, e.g., (des)activation mechanisms in metabolic networks, the dynamic behavior is of importance. Therefore techniques of dynamic Metabolic Flux Analysis (dMFA) and dynamic Flux Balance Analysis (dFBA) are developed for the estimation and prediction respectively of intracellular fluxes. In this study an alternative dMFA approach is adopted and validated with example metabolic networks.

The presented method is based on a B-spline parameterization of the fluxes. State-of-the-art methods and tools are used for the dynamic optimization problems that are encountered in this dMFA approach: automatic differentiation with CasADi, interior point optimization with IPOPT and an orthogonal collocation scheme. The validation of this method is done with several case studies involving (des)activation in metabolic networks.

TuE02-5 **18.10–18.35**

On biological feasibility of solutions in a novel mathematical model for testosterone regulation

Hadi Taghvafard Rijksuniversiteit Groningen
Anton V. Proskurnikov Rijksuniversiteit Groningen
Ming Cao Rijksuniversiteit Groningen

In this paper, we deal with a new mathematical model for testosterone regulation. The model involves concentrations of three hormones: testosterone (Te), the luteinizing hormone (LH) and gonadotropin-releasing hormone (GnRH). In previous models, the secretion of GnRH stimulates that of LH which, in turn, stimulates the production of Te, while Te inhibits the secretion of GnRH. There is, however, experimental evidence that testosterone also inhibits the production of LH. This motivates us to introduce a novel model for testosterone regulation, employing a linear negative feedback from Te to LH. This feedback, however, breaks the positivity of the system and gives rise to the question which solutions are biologically feasible. In this paper, we give sufficient conditions for such feasibility.

TuE03 **Impresario**

Identification II

Chair: Anna Marconato **Tuesday, 16.30–18.35**

TuE03-1 **16.30–16.55**

Identification of Linear Time Varying Systems using 2D Regularization

Péter Zoltán Csurcsia Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel
John Lataire Vrije Universiteit Brussel

This paper presents a methodology to obtain an impulse response function estimate of a time varying system using 2D regularization. A powerful time domain estimation method is developed for smooth linear time varying systems. This technique is illustrative, flexible, user friendly. With respect to the system dynamics using the proposed method, it is possible (i) to reduce the model order; and (ii) to decrease the effect of the disturbing noise.

TuE03-2 **16.55–17.20**

Identification for Control of High-Tech Motion Systems

Robbert Voorhoeve TU Eindhoven
Tom Oomen TU Eindhoven

In future high-tech motion system, a systematic model based control approach is essential. System identification is the natural approach for the modeling of such systems. However, the identification of parametric models still poses a major challenge in practice. One of the challenging aspects is the numerical reliability of the identification algorithms. In this work a numerically reliable identification approach, as well as several pre-existing approaches, are implemented and experimentally investigated for the SISO identification of a high-tech motion system. The results clearly indicate that the numerical issues are already present in this SISO case, showing the relevance and challenge of numerically reliable identification.

TuE03-3 **17.20–17.45**

Measuring nonlinear distortions: from test case to an F-16 Fighter

M. Vaes Vrije Universiteit Brussel
J. Schoukens Vrije Universiteit Brussel
Y.Rolain Vrije Universiteit Brussel
B. Peeters, J. Debille, T. Dossigne, J.P. Noël, C. Grappasonni, G. Kerschen

What are the similarities and differences between the behavior of a small vibrating test system and an F-16 fighter? To find it out, we compare measurements of the test system to measurements from the bolted connection of the wing and the missile of a F-16 Fighter Falcon from the Belgian air force. These measurements were done during a ground vehicle test (GVT) campaign. Essentially, the behavior of these systems match, even though the test system

is only the heart of a self-study kit for nonlinear system identification and the F-16 is a complex real life mechanical structure. This clearly shows the added value of an experiment driven nonlinear educational system identification package. It provides safe small-scale toy examples for hands-on exercises that react like real systems. We believe that this practical approach lowers the gap between learning system identification concepts and applying it on real systems.

TuE03-4 **17.45–18.10**

Study of the control of a UAV/UGV cooperative system manipulating an object

Tam Nguyen Université Libre de Bruxelles
Emanuele Garone Université Libre de Bruxelles

This contribution focuses on the control of a heterogeneous system composed of an Unmanned Aerial Vehicle (UAV) and an Unmanned Ground Vehicle (UGV). The two units need to cooperate to manipulate an object. The UAV and UGV are both subject to saturation constraints. The objective is to design a control law able to steer the system to a configuration of equilibrium. It is assumed that no communication is exchanged between the two vehicles and that only angle sensors are used. The stability of the automated system is proven using ISS arguments and the small gain theorem. The use of a reference governor is proposed to ensure constraints satisfaction during the transients.

TuE03-5 **18.10–18.35**

Compact representations of large dynamical systems based on low-rank tensor approximations

Martijn Boussé KU Leuven
Otto Debals KU Leuven
Lieven De Lathauwer KU Leuven

In many applications we want to identify a system of which we do not know the inputs; this is called blind system identification (BSI). Existing methods, however, cannot cope with the rise of large-scale systems (big data). Higher-order tensors provide remarkable possibilities for the compact representation and identification of such systems.

TuE04 **Bloemen**

Control I

Chair: Benjamin Biemond **Tuesday, 16.30–18.35**

TuE04-1 **16.30–16.55**

A switched systems approach to (de-)stabilization of predator-prey tumor dynamics

Alina Doban TU Eindhoven
Mircea Lazar TU Eindhoven

In this work, we propose a systematic cancer therapy strategy, which is based on switching between successive parameter dependent domains of attraction. More specifically, we address the problem of steering a stable invasive tumor to tumor dormancy. A predator -prey model from the literature is considered for describing the tumor-normal cells interaction. For computing the domain of attraction of an equilibrium of interest, maximal rational Lyapunov functions are employed, which can be systematically computed for nonlinear systems. The proposed procedure confirms observations from medical practice and provides a useful tool for cancer therapy design and testing.

TuE04-2 **16.55–17.20**

Synchronization of Goodwin-type oscillators under saturated control

Anton V. Proskurnikov Rijksuniversiteit Groningen
Ming Cao Rijksuniversiteit Groningen

Many processes in living organisms, including circadian clocks and hormonal regulation, are controlled by ensembles of biochemical oscillators, synchronized by some physical coupling. In the recent paper by Hamadeh et al. (2012) an important step in examining synchronization phenomenon for biochemical oscillators has been done. A criterion for synchronization of identical oscillators under linear diffusive couplings was proposed, which is based on the property of incremental passivity and states that the system of such oscillators renders synchronized by a static diffusive couplings, provided that their strength (the algebraic connectivity of the network) is large. The application of this criterion to most of real biochemical oscillators may, however, be troublesome, since it eventually assumes that solutions are bounded. Furthermore, to design a synchronizing protocol, one has to know passivity gains of the

constituent blocks, that are to be finite and employed by the formula for the critical coupling strength. However, finite passivity gains may be guaranteed only in a finite domain; to choose a linear protocol, providing the solutions to stays in such a domain, is a quite nontrivial problem. Instead, we modify the protocol by Hamadeh et al., introducing a bounded "saturation map". This allows to separate two goals: boundedness of the solution (achieved due to saturated control) and synchronization. We prove that oscillators get synchronized under strong coupling.

TuE04-3 **17.20–17.45**

Estimation of basins of attraction for controlled systems with input saturation and time-delays

J.J.B. Biemond KU Leuven
W. Michiels KU Leuven

Basins of attraction are instrumental to study the effect of input saturation in control systems, as these sets characterise the initial conditions for which the control strategy induces attraction to the desired equilibrium. In this paper, we describe these sets when the open-loop system is exponentially unstable and the system is controlled by a single actuator with both constant time-delays and saturation. Estimates of the basin of attraction are provided and the allowable time-delay in the control loop is determined with a novel piecewise quadratic Lyapunov-Krasovskii functional that exploits the piecewise affine nature of the system. As this approach leads to sufficient, but not to necessary conditions for attractivity, we also present simulations of an example to show the applicability of the results.

TuE04-4 **17.45–18.10**

Design of periodic event-triggered control for nonlinear systems using overapproximation techniques

D.P. Borgers TU Eindhoven
R. Postoyan Univ-Lorraine
W.P.M.H. Heemels TU Eindhoven

In event-triggered control (ETC) systems, the triggering condition has to be monitored continuously, which is not possible on digital platforms. This work proposes a method to turn any nonlinear ETC system into a periodic event-triggered control (PETC) system, which can be implemented on digital platforms.

TuE04-5 **18.10–18.35**

On delta-sampling verification for discrete-time systems

Ruxandra Bobiti TU Eindhoven
Mircea Lazar TU Eindhoven

The problem of safety verification for discrete-time, possibly discontinuous dynamical systems is considered. Typical solutions rely on finding invariant sets or Lyapunov functions and require solving optimization problems, which suffer from scalability and numerical solvers issues. Recently, an alternative method for verifying invariance for Lipschitz-continuous dynamics was proposed, which does not make use of optimization. This method allows verification of the invariance of a set by verification for only a finite number of points in the set, called a delta-sampling of the set. Here, a delta-sampling verification result is proposed for extending the previous result to general discrete-time, possibly discontinuous dynamics. This opens up the application of delta-sampling verification to hybrid systems.

WeM01 **Les Arcades**

Optimization II

Chair: Michel Kinnaert **Wednesday, 09.00–11.05**

WeM01-1 **09.00–09.25**

About the latest complexity bounds for Policy Iteration

Romain Hollanders Université catholique de Louvain
Balázs Gerencsér Université catholique de Louvain
Jean-Charles Delvenne Université catholique de Louvain
Raphaël M. Jungers

The Policy Iteration algorithm (PI) is probably the most effective way of solving Markov Decision Processes. In this talk, I will present what we know about the complexity of PI and make the link with the closely related Simplex algorithm for Linear Programming. The question of bounding the number of iterations of PI has remained a challenge for about 50 years but lately, several major results have been popping up. I will present how we tackled the problem using new insightful combinatorial tools. Spoiler alert: the Fibonacci sequence is not the answer.

WeM01-2 **09.25–09.50**

Mixing time speedup by some added edges and non-reversibility

Balázs Gerencsér Université catholique de Louvain
Julien Hendrickx Université catholique de Louvain

We aim for constructing fast mixing Markov chains given the graph of allowed transitions. We show that adding a few edges can help a lot, and also breaking the reversibility (symmetry) of the Markov chain substantially improves the performance.

WeM01-3 **09.50–10.15**

Robust Gradient Learning with Application to Nonlinear Variable Selection

Yunlong Feng KU Leuven
Yuning Yang KU Leuven
Johan A.K. Suykens KU Leuven

The gradient learning (GL) model aims at learning the gradients of the regression function, which is directly driven by variable selection and coordinate covariance problems. However, in real-life applications, data sets might be contaminated by outliers or heavy-tailed noise, which may appear in both response or the predictors. In this case, the GL model cannot help in learning gradients. In our study, we present a framework of robust gradient learning (RGL) model to learn the gradients of the regression function robustly.

WeM01-4 **10.15–10.40**

Influence of uncertainty on temporal stabilizability and compensatability of linear systems with white stochastic parameters

L.G. Van Willigenburg Wageningen UR
Willem de Koning

tms-Stabilizability and tms-compensatability identify intervals where mean-square stability (ms-stability) of the closed loop system cannot be achieved when state respectively output feedback control is applied to time-varying linear systems having white stochastic parameters. Here an illustrative example is presented showing how increased parameter uncertainty degrades tms-stabilizability and tms-compensatability.

WeM01-5 **10.40–11.05**

Online semi-supervised clustering regularized by Kalman filtering

Siamak Mehrkanoon KU Leuven
Oscar Mauricio Agudelo KU Leuven
Johan A. K. Suykens KU Leuven

An on-line semi-supervised learning algorithm formulated as a regularized kernel spectral clustering (KSC) approach is proposed. Given a few user-labeled data points the initial model is learned and then the class membership of the remaining data points in the current and subsequent time instants are estimated and propagated in an on-line fashion. Furthermore we show how the tracking capabilities of the Kalman filter can be used to provide the labels of

objects in motion and thus regularizing the solution obtained by the MSS-KSC algorithm.

WeM02	**Emanuel**
MPC	
Chair: Jacquelien Scherpen	**Wednesday, 09.00–11.05**

WeM02-1 **09.00–09.25**

Data driven MPC based on OBF model structures

Ahmad Alrianes Bachnas TU Eindhoven
Siep Weiland TU Eindhoven
Roland Tóth TU Eindhoven
A.A. Bachnas

In this work, a novel solution is proposed by employing a flexible model structure, namely an orthonormal basis function (OBF) model structures into the MPC scheme. Due to its model characteristics, structured model updates can be conducted iteratively in a closed loop setting via latest measured input-output data. Small updates towards model coefficients are done iteratively to fine tune the prediction part of the control scheme. If the change of the plant and/or disturbances persist for a long period, model overhaul is conducted by re-updating the basis functions. This will reduce the modeling uncertainty to ensure that the plant can still be accurately described by the selected basis functions. Moreover, since OBF model structures can be seen as a generalization of FIR model structures, the wide application of FIR model in the industrial MPC scheme is another appealing reason for the proposed solution.

WeM02-2 **09.25–09.50**

Distributed Model Predictive Control of Aquifer Thermal Energy Storage Smart Grids

Vahab Rostampour TU Delft
Tamas Keviczky TU Delft

Aquifer Thermal Energy Storage (ATES) systems are used to store large quantities of thermal energy in underground aquifers enabling the reduction of energy usage and CO2 emissions of the heating and cooling systems in buildings. In dense urban environments, the proximity of hot and cold wells in nearby ATES systems installations may lead to undesired interactions between such energy storage systems leading to suboptimal operation or conservative design choices.

WeM02-3 **09.50–10.15**

Distributed MPC in the Universal Smart Energy Framework

D. Bao Nguyen Rijksuniversiteit Groningen
Jacquelien M.A. Scherpen Rijksuniversiteit Groningen

Environmental concerns have prompted a shift towards the usage of renewable energy resources, such as wind or solar energy. Windmills and solar panels are, however, often spatially distributed, hence the energy production itself also becomes distributed. This presents a paradigm shift from the traditional, centralized generation. Furthermore, renewable energy resources depend on weather conditions which results in a fluctuating production and creates an imbalance between supply and demand. The problem can be addressed by demand response, in which the consumer side is also playing an active role in the balancing process. To facilitate the development of smart energy services, the Smart Energy Collective (SEC) is setting up a standardized platform in the Netherlands, called the Universal Smart Energy Framework. USEF introduces flexible households that are equipped with appliances capable of moving their load demand and thus change their energy consumption in time. We describe a distributed model predictive control scheme to balance between supply and demand in a network of flexible households and demonstrate the large-scale feasibility of the method via MATLAB simulation.

WeM02-4 **10.15–10.40**

Energy-optimal point-to-point motions with high positioning accuracy using offset-free energy-optimal MPC

Xin Wang KU Leuven
Jan Swevers KU Leuven

Offset-free Energy-optimal Model Predictive Control (offset-free EOMPC) is developed based on our previous research - Energy-optimal Model Predictive Control (EOMPC) to improve its positioning accuracy in the presence of unmodelled disturbances. This is realized by augmenting the system state with disturbance variables such that the

disturbances are estimated and the effects of which are cancelled. Experimental validation of the offset-free EOMPC is implemented on a linear motor with coulomb friction and cogging disturbances.

WeM02-5 **10.40–11.05**

Anticipative linear parameter-varying model predictive control

J. Hanema TU Eindhoven
R. Tóth TU Eindhoven
M. Lazar TU Eindhoven
S. Weiland

This paper discusses model predictive control (MPC) for linear parameter-varying (LPV) systems. We will carry out fundamental research on the achievable levels of performance of LPV-MPC algorithms which (i) use exact or partial knowledge on the behaviour of the scheduling parameter; (ii) are robust against modelling mismatch and unmeasured disturbances; and (iii) are computationally simple to allow for real-time implementation. The results of the research will be applied for thermal control of the wafer table in a lithography machine.

WeM03 **Impresario**

Identification III

Chair: Johan Schoukens **Wednesday, 09.00–11.05**

WeM03-1 **09.00–09.25**

Modeling Circadian Rhythm using Coupled Semipassive Systems

Isaac Castanedo Guerra TU Eindhoven
Henk Nijmeijer TU Eindhoven

The biological clock regulates 24-h rhythms in our body. This clock is located in the suprachiasmatic nucleus (SCN). The output entails a 24-h rhythm in electrical impulse frequency with a higher frequency during the day and a lower frequency during the night. There is evidence that individuals neurons within the SCN act as circadian oscillators. Due to local coupling the oscillators synchronize and an overall rhythm emerges.

WeM03-2 **09.25–09.50**

Optimizing Inputs for Nonlinear Systems with Infinite Memory in the Time Domain

Alexander De Cock Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel

The main goal of this work is to obtain a better understanding of what makes an input informative in the case of nonlinear infinite memory systems. However, unlike linear dynamic systems or nonlinear finite memory systems, no global or convex solver is known for this problem. Therefore, a brute force optimization will be performed where the time samples of the input are optimized with the help of numerical nonlinear solvers. In order to avoid local maxima, the settings of the optimization problem need to be carefully chosen. Three important settings will be considered: the total signal length, the sampling frequency and the initial values of the optimization.

WeM03-3 **09.50–10.15**

A MATLAB toolbox for optimizing splines

Wannes Van Loock KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers KU Leuven

We present a novel MATLAB toolbox for modelling and solving optimization problems involving splines. Semi-infinite constraints are imposed by a finite set of conservative constraints on the spline coefficients. Furthermore, relaxations are proposed to control the degree of conservatism. Two examples originating from optimal control and combined structure and control design will illustrate the software's capabilities.

WeM03-4 **10.15–10.40**

Modeling and control of heat networks with storage: the single-producer multiple-consumer case

T.W. Scholten Rijksuniversiteit Groningen
C. De Persis Rijksuniversiteit Groningen
P. Tesi Rijksuniversiteit Groningen

In heat networks, energy storage is a viable approach to balance demand and supply. In such networks, a heat carrier is used in the form of water, where heat is injected and extracted through heat exchangers. The network can transport heated water and store it in stratification tanks. A setpoint tracking problem is defined in which a desired amount of energy is stored in the storage tank while satisfying a, possible time varying, demand. A setup is considered which includes a single producer with a storage tank and multiple consumers.

WeM03-5 **10.40–11.05**

Design of experiment approach for optimizing the characteristics of the excitation signal for discriminating the internal structure

Alireza F. Esfahani Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel
Laurent Vanbeylen Vrije Universiteit Brussel

Nonlinear (NL) system identification is a high demanding field. Several NL system identification algorithms require very high quality frequency response functions (FRFs). These are used to generate an initializing estimate of the model in the optimization stage. In this work a practical method, based on design of experiment (DOE) is proposed to generate optimal quality FRFs. The proposed method tunes the DC and standard deviation (STD) levels of the excitation signal in a sense, to have an FRF (BLA, the best linear approximation) with minimum distortion level.

WeM04 **Bloemen**

Systems Theory I

Chair: Geert Gins **Wednesday, 09.00–11.05**

WeM04-1 **09.00–09.25**

A Tensor-based Framework for Blind Identification of Linear MIMO FIR Systems

Frederik Van Eeghem KU Leuven
Otto Debals KU Leuven
Lieven De Lathauwer KU Leuven

Blind system identification (BSI) tries to identify a system using only the outputs. This is useful when the input data are expensive or impossible to measure, as is the case in several medical applications, wireless communications and the processing of seismographic data. However, it is not possible to blindly identify systems without making some extra assumptions. Here, the inputs are assumed to be statistically independent. We tackle the BSI-problem using tensor decompositions, which have useful properties that are not present in vectors and matrices. By relating different cases of BSI to tensor decompositions, a full tensor-based framework for BSI is obtained. This framework enables us to use the theory developed for tensor decompositions in a BSI context.

WeM04-2 **09.25–09.50**

Applications of the greatest common divisor in system theory and signal processing

Ivan Markovsky Vrije Universiteit Brussel
Mayank Saxena Vrije Universiteit Brussel

We consider the problem of computing the greatest common divisor of a set of univariate polynomials and present applications of this problem in systems, control, and signal processing. One application is blind system identification: given the responses of a system to unknown inputs, find the system. Assuming that the unknown system is finite impulse response and at least two experiments are done with inputs that have finite support and their Z-transforms have no common factors, the impulse response of the system can be computed up to a scaling factor as the greatest common divisor of the Z-transforms of the outputs. Other applications of the greatest common divisor in system theory are: - checking controllability of a single-input single-output linear time-invariant system, - computing minimal kernel representation of an autonomous linear time-invariant system, - finding the intersections of (autonomous) behaviors, - detection of spurious poles in operational modal analysis, and - separation of a disturbance shaping filter from the system's dynamics. The solution tools that we use are low-rank Hankel and Sylvester structured matrix computations.

WeM04-3 **09.50–10.15**

A survey on stochastic and deterministic tensorization for blind signal separation

Otto Debals KU Leuven Kulak
Lieven De Lathauwer KU Leuven Kulak

The Blind Signal Separation problem consists of the identification of some source signals and mixing vectors given only the observed signals. Using standard matrix factorizations such as the well-known singular value decomposition or the QR/LQ decomposition is not recommended because of the unsuitable constraints they incorporate. More suitable techniques have been presented during recent years of which a lot have strong connections with multilinear algebra, as the observed data matrix is often tensorized, i.e., transformed to a tensor. We present a couple of those techniques, such as the use of Higher-Order Statistics for ICA, the use of Loewner matrices for the separation of rational functions and the use of segmentation for the separation of low-rank representations.

WeM04-4 **10.15–10.40**

Identifying Parameters with Pre-Specified Accuracies in Linear Physical Systems: Part I

Max Potters TU Delft
Xavier Bombois TU Delft
Paul M.J. Van den Hof TU Eindhoven

In this presentation we introduce the concept Least-Costly Experiment Design and discuss two optimization problems: cost minimisation with (i) n-dim ellipsoidal constraints, and with (ii) n-dim box constraints. We discuss their differences and provide some analytical solutions for the two cases.

WeM04-5 **10.40–11.05**

Identifying Parameters with Pre-Specified Accuracies in Linear Physical Systems: Part II

Max Potters TU Delft
Mehdi Mansoori TU Delft
Xavier Bombois TU Delft
Paul M.J. Van den Hof

In this presentation we apply Least-Costly Experiment Design framework to the identification of linear physical systems, which are often driven by Partial Differential Equations (PDEs). We explain the differences between these systems and ones that are driven by ordinary differential equations (ODEs). We show how the experiment design framework can be applied to PDE systems. We furthermore introduce a new algorithm that, next to optimal frequencies and amplitudes, also finds optimal actuator and sensor locations. Lastly, we apply the framework to the identification of two physical parameters in a front-face experiment.

WeM05 Seaside

Control Applications I

Chair: Goele Pipeleers **Wednesday, 09.00–11.05**

WeM05-1 **09.00–09.25**

Distributed supply coordination for Power-to-Gas facilities embedded in the energy grids

Desti Alkano Rijksuniversiteit Groningen
Ilco Kuiper Rijksuniversiteit Groningen
Jacquelien M.A. Scherpen Rijksuniversiteit Groningen

This study proposes a distributed supply coordination for Power-to-Gas facilities embedded in a gas grid, mobility sector, and power grid. The fairness of the proposed algorithm is studied. Extensive simulation results using realistic data provide some insights on how a dynamic pricing mechanism helps to avoid overloading energy grids.

WeM05-2 **09.25–09.50**

Handling uncertainties in balancing short-term and long-term objectives in water-flooding optimization

Muhammad Mohsin Siraj TU Eindhoven
Paul M.J. Van den Hof TU Eindhoven
Jan Dirk Jansen TU Delft

Water-flooding involves the injection of water in an oil reservoir to increase oil production. Dynamic optimization of the water-flooding process has shown significant scope for improvement of the economic life-cycle performance of oil

fields. The financial measure, Net Present Value (NPV) used in this optimization process, because of its cumulative nature, focuses on the long-term gains while the short-term production is not explicitly addressed. At the same time the achievable NPV is highly uncertain due to the limited knowledge of reservoir model parameters and the varying economic conditions. Different (ad-hoc) methods have been proposed to introduce short-term considerations to balance short-term and long-term objectives in a model-based approach. In this work, we address the question whether through an explicit handling of model and economic uncertainties in NPV (robust) optimization, an appropriate balance between these economic objectives is naturally obtained.

WeM05-3 **09.50–10.15**

Analysis and Synthesis of Interconnected Systems: Application to Tuned Vibration Absorber Design for a Flexible Beam

Ruben Van Parys KU Leuven
Goele Pipeleers KU Leuven

Since the last decade, substantial research has been devoted to the analysis and synthesis of interconnected systems by addressing techniques from robust systems theory. An important result is the convex reformulation of the distributed controller design problem, for which the controller has the same interconnection scheme as the plant and the controller subunits having the same order as the ones on the plant. However, this controller type is not always applicable. In some cases, it is desired to synthesize controllers with a much lower degree or with a free interconnection topology. In this work, two strategies are explored to solve structured distributed control problems. These are applied on the design of tuned vibration absorbers for a flexible beam.

WeM05-4 **10.15–10.40**

State-Dependent Virtual Hierarchization of Batteries and Its Application to Energy Management Systems

Hitoshi Yanami Fujitsu Ltd.
Tomotake Sasaki Fujitsu Ltd.
Junji Kaneko Fujitsu Ltd.
Shinji Hara

We propose a three-layered state-dependent virtual hierarchization of the batteries in energy network systems and a glocal control algorithm based on the structure. Computational experiments are shown to demonstrate the effectiveness of our algorithm.

WeM05-5 **10.40–11.05**

Extended and unscented Kalman filter designs for hybridoma cell fed-batch cultures

Sofia Fernandes UMons
Anne Richelle Université Libre de Bruxelles
Zakaria Amribt Université Libre de Bruxelles
Laurent Dewasme

In the present study, both extended (EKF) and unscented (UKF) kalman filters are applied to hybridoma cell cultures to estimate glucose and glutamine concentrations, using a macroscopic model taking account of an overflow metabolism within glycolysis and glutaminolysis. In many study cases, sensitivity of measured model states to unmeasured ones is low, leading to poor estimation quality. This is due to the fact that when using least-squares method to identify model parameters, no guarantee is provided about sensitivity. To overcome this problem, a parameter identification procedure is proposed in (P. Bogaerts and A. Vande Wouwer, 2004), which is based on a cost function combining the usual least-squares criterion with a state estimation sensitivity criterion. The motivation of this work is to show the effectiveness of the parameter identification for state estimation procedure when state observability is limited.

Plenary: P2	**Les Arcades**
Dynamics and control of particulate processes **Achim Kienle**	
Chair: Filip Logist	**Wednesday, 11.30–12.30**

Particulate products like crystals, granules, powders play a major role in process industries. Typical examples are pharmaceuticals, detergents, pigments, polymers etc. They represent about 60% of the produced value in the chemical industry. Typical production processes comprise crystallization, granulation, polymerization etc. Function and effectiveness of particulate products often depend on particle properties - such as size, porosity, morphology or composition. Main objective of our research in this field of application is to devise new methods and tools for modeling and control of particulate processes aiming at adjustment of desired product properties.

This is a challenging issue due to nonuniformity of particle systems, where particles differ with respect to individual properties, and product properties are represented by the collective behavior of the particle population. From the theoretical point of view particulate processes belong to a special class of distributed parameter systems, so called population balance systems. They are described by nonlinear partial differential equations often coupled to integro differential equations describing the surrounding medium.

The talk will address main challenges for modeling and control of particulate processes and present some solution approaches developed in our group in recent years. Theoretical concepts will be illustrated with practical application examples including crystallization and granulation processes.

WeP01	**Les Arcades**
Control over Networks	
Chair: Maurice Heemels	**Wednesday, 14.00–16.05**

WeP01-1 **14.00–14.25**

Correct-by-Design Control of Physical Systems, Separating Estimation and Control

Sofie Haesaert TU Eindhoven
Paul Van den Hof TU Eindhoven
Alessandro Abate Oxford University

Verifiable design methods such as correct-by-design controller synthesis allow for the safe construction of controlled systems that satisfy properties expressed within a formal language. In this work we look at the implications in case the current available work is extended to output based controllers.

WeP01-2 **14.25–14.50**

Complete Vehicle Energy Management with Large Horizon Optimization

T.C.J. Romijn TU Eindhoven
M.C.F. Donkers TU Eindhoven
S. Weiland TU Eindhoven
J.T.B.A. Kessels

In this abstract, we extend the dual decomposition approach to complete vehicle energy management (CVEM) with novel solution methods to improve computational performance. The proposed extensions enable solving the CVEM problem over very large horizons for measuring its benefit for long-haul applications.

WeP01-3 **14.50–15.15**

Enterprise-wide Optimization: Graph Constrained Scheduling

M. Bahadir Saltik TU Eindhoven
Nikolaos Athanasopoulos TU Eindhoven
Leyla Özkan TU Eindhoven

The aim of this work is to introduce graphs to reduce the complexity of scheduling algorithms that are conducted for enterprise-wide optimization. The scheduling decisions when to turn-on or when to turn-off an unit operation (UO), a subprocess of a large-scale system, is the main research topic. In order to reduce the inherent complexity, we follow a modeling approach of the scheduling logic rules on labeled directed graphs. The decision tree is greatly reduced (w.r.t. unconstrained case) by making use of graphs of each UO. Then, by utilizing forward reachability

algorithms, we find the all possible trajectories, which distinguishes the infeasible (undesired) and feasible schedules. The proposed approach is implemented on a separation process.

WeP01-4 **15.15–15.40**

Feedback Control Design for Systems with Data-Intensive Sensing

E.P. van Horssen TU Eindhoven
D.J. Antunes TU Eindhoven
W.P.M.H. Heemels TU Eindhoven

The aim of this work is first to give an overview of the challenges of data-intensive feedback control. Second, research directions are presented on how these challenges can be handled. Inspiration is drawn from the tools used for hybrid, switched and networked control systems. Third, examples of applications are discussed to show how these methods can be used.

WeP01-5 **15.40–16.05**

Sub-Optimal Strategies for Output-Based Event-Triggered Control

B. Asadi Khashooei TU Eindhoven
D.J. Antunes TU Eindhoven
W.P.M.H. Heemels TU Eindhoven

Recent research advocates that replacing the periodic communication paradigm by an event-triggered paradigm can have signicant benets for control systems. Here we propose an optimization-based output-feedback event-triggered solution for linear discrete-time systems which guarantees a performance that is within a certain factor of all-time transmission control, while reducing the communication load signicantly.

WeP02 **Emanuel**

Optimal Control

Chair: Wannes Van Loock **Wednesday, 14.00–16.05**

WeP02-1 **14.00–14.25**

Bringing optimal feedback controller design to practice

Maarten Verbandt KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers KU Leuven

Although optimal feedback controller design based on H or H2 criteria as already proven its potential in academia, it has yet to find wide acceptance in industry. One explanation is the lack of software support for practitioners without expertise in optimal control. Matlabs robust control toolbox contains the core tools for H and H2 control, but (i) it doesnt allow for an easy and intuitive control problem formulation; (ii) it doesnt support multi-objective controller designs; (iii) it doesnt allow for unstable or improper weights. To overcome these drawbacks we are developing a Matlab toolbox that combines an intuitive control problem formulation with efficient and numerically stable algorithms that overcome the drawbacks mentioned above.

WeP02-2 **14.25–14.50**

Application of Tensor Decomposition Based Reduction for Dynamic Programming

Julian Stoev Flanders Make
Steve Vandenplas Flanders Make

Dynamic programming (DP) is a well known approach with many applications, among them optimal control. This work aims to reduce some of the disadvantages of DP by using tensor decomposition based reduction of the look-up tables. They can be arranged in the form of multidimensional tensor. Higher-order singular value decomposition is then performed on it, resulting in a reduced core tensor and a set of one-dimensional look-up tables. The memory required to store these is reduced with respect to the original look-up table.

WeP02-3 **14.50–15.15**

Optimal tracking gain computation for mechanical systems with unilateral constraints

Mark Rijnen TU Eindhoven
Alessandro Saccon TU Eindhoven
Henk Nijmeijer TU Eindhoven

Trajectory tracking for mechanical systems with unilateral constraints is considered. These systems can be casted in the framework of hybrid systems with jump-flow characteristics. The local behavior about a reference can be described by a specific time-triggered jumping linear system, which is employed to compute an optimal feedback control based on LQR theory. A controlled bouncing mass is considered as test case and it is found that the position feedback gain can, suprisingly, become negative for a short amount of time before impact.

WeP02-4 **15.15–15.40**

Time-optimal motion planning in the presence of moving obstacles

Tim Mercy KU Leuven
Wannes Van Loock KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers

Autonomous motion systems are becoming more and more popular in industry. Some examples are AGV's, fruit picking robots, drones and autonomous cars. To drive these systems, one generally wants to compute the fastest or the most energy efficient motion trajectory to move the system from its current position to its destination while obeying input and state constraints and avoiding collision with obstacles in the environment. This motion trajectory is typically computed by solving an optimization problem. As autonomous systems often operate in environments with moving obstacles of which the motions are not fully known a priori, the trajectory needs to be updated in real time. This abstract presents a method for calculating a time-optimal motion trajectory in the presence of moving obstacles. The method has two key aspects: (i) via a B-spline parametrization of the motion trajectory it is possible to make a trade-off between the complexity of the optimization problem and the optimality of the resulting trajectory; (ii) the properties of B-splines allow to transform all constraints to conservative constraints on the B-spline coefficients. This relaxation lowers the amount of constraints. These aspects lead to a small scale optimization problem that is suitable for real-time implementation. The method has been tested extensively by numerical simulations. In addition, it has been validated in an experimental demo where a KUKA youBot moved time-optimally from one

WeP02-5 **15.40–16.05**

It's not MPC ! An Explicit Reference Governor for the supervision of constrained nonlinear systems

Marco M Nicotra Université Libre de Bruxelles
Emanuele Garone Université Libre de Bruxelles

This talk introduces a novel control law that dynamically modifies the reference of a pre-compensated nonlinear system so as to ensure the satisfaction of convex constraints without resorting to online optimization. This is done by translating state space constraints into a constraint on the Lyapunov function and limiting its value by modulating the velocity of the applied reference.

WeP03 **Impresario**

Identification IV

Chair: Johan Schoukens **Wednesday, 14.00–16.05**

WeP03-1 **14.00–14.25**

Irradiance Models for Projection Optics

R.W.H. Merks TU Eindhoven
M.B.I. Habets TU Eindhoven
S. Weiland TU Eindhoven
W.M.J.M. Coene

Thermally induced deformations of optical elements influence the performance of high precision optical projection systems. For extreme ultraviolet lithography, the mirrors each absorb approximately 35% of the incident power. The thermally induced deformations are for this reason mainly a result of the irradiance on the mirrors. In order to determine and predict the induced deformations for design as well as control purposes irradiance models can be utilized.

WeP03-2 **14.25–14.50**

Multi-Tone Synthesis of RF Power Amplifiers

Piet Bronders Vrije Universiteit Brussel
Gerd Vandersteen Vrije Universiteit Brussel

Efficiency enhanced power amplifiers (PA), such as the Doherty PA, the Envelope Tracking (ET) technique and many others, are either designed by using exquisite nonlinear models or more generally with the help of a simple one tone excitation that heavily simplifies the PA behaviour, ignoring the dynamical behaviour that such devices demonstrate. This work proposes the use of multi-tone excitations as a trade-off between complexity and oversimplification. This in the hope that a first pass solution is attained that gives a more performing result than classical one tone design techniques and permits a greater extent of control to the designer.

WeP03-3 **14.50–15.15**

Kalman filter based reconstruction and robust control of the plasma density in tokamaks

Thomas Blanken FOM-institute DIFFER
Federico Felici TU Eindhoven
Marco de Baar FOM-institute DIFFER
Maurice Heemels

An observer and a feedback controller are presented which can reconstruct and control the density profile of a tokamak plasma. A control-oriented, model-based approach is employed to design a Kalman filter and a feedback controller using robust control theory. Offline reconstruction simulations using tokamak measurements indicate accurate density estimation and demonstrate the tuning tradeoffs. Simulations of the closed loop promise satisfactory tracking performance.

WeP03-4 **15.15–15.40**

Regularized Nonparametric Volterra Kernel Estimation

Georgios Birpoutsoukis Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel

One way to describe the nonlinear behavior of a process is by use of the nonparametric Volterra series representation. The major advantage lies in the fact that the problem of choosing the appropriate nonlinear model structure is bypassed. Unfortunately it comes at the cost that the number of parameters to be estimated increases fast for increasing memory of the several impulse responses. This results in a very large variance for the estimated parameters leading to a poor description of the system dynamics, unless very long data records are available. In this work, we present a method to estimate efficiently finite Volterra kernels without the need of long records, based on the regularization methods that have been developed for the one-dimensional (1-D) impulse responses for linear time invariant (LTI) systems.

WeP03-5 **15.40–16.05**

Nonlinear System Identification of Hydrostatic Drivetrain

Julian Stoev Vrije Universiteit Brussel & Flanders Make
Johan Schoukens Vrije Universiteit Brussel

It is of practical interest to apply nonlinear system identification to diverse industrial cases and gain understanding how it compares with existing linear methods in situations close to real-life. The test set-up for this work comprises a large hydrostatic drive train. The system is MIMO, time-varying and non-linear.

WeP04 — Identification V — Bloemen

Chair: Ivan Markovsky **Wednesday, 14.00–16.05**

WeP04-1 **14.00–14.25**

FRF Smoothing Improves the Initial Values for Transfer Function Estimation

Egon Geerardyn Vrije Universiteit Brussel
John Lataire Vrije Universiteit Brussel

Estimating a parametric transfer function model, often boils down to a non-convex optimization problem. Hence, good starting values are required to obtain good models. When noisy input-output data are used, the optimization

procedures often get stuck in local optima, resulting in sub-optimal or even poor parametric estimates. In this talk, the use of non-parametric smoothers is investigated to improve the starting values in a parametric identification step. In particular, a method based on the Local Polynomial Method (LPM) and regularized finite impulse response (RFIR) estimation are compared to BTLS and GTLS (respectively Bootstrapped and Generalized Total-Least-Squares) for both measurement and simulation examples. Non-parametric FRF smoothers indeed allow to obtain improved starting values for parametric identification. This results in significantly improved parametric estimates, without increasing the required user interaction.

WeP04-2 **14.25–14.50**

Characterization and Nonlinear modelling of Li-Ion battery

Rishi Relan Vrije Universiteit Brussel
Laurent Vanbeylen Vrije Universiteit Brussel
Yousef Firouz Vrije Universiteit Brussel
Johan Schoukens

Lithium ion (Li-ion) batteries are attracting significant and growing interest because their high energy and high power density render them an excellent option for energy storage, particularly in hybrid and electric vehicles as well as an ideal candidate for a wide variety of applications. Some limitations of existing Li-ion battery technology include under-utilization, stress-induced material damage, capacity fade, and the potential for thermal runaway. In order to develop a complete dynamic model of a lithium ion battery that is suitable for virtual-prototyping of portable battery-powered systems, accurate estimation of the state of charge (SOC) and state of health (SOH) is required, which in-turn depends on the quality of the models which are used for the estimation of these quantities. In this paper, a data-driven polynomial non-linear state-space model (PNLSS) is proposed for the non-linear regime of the batterys electrical operation based on a non-parametric characterization of the batterys behaviour.

WeP04-3 **14.50–15.15**

SMA-actuated catheter systems

Rolf Gaasbeek TU Eindhoven

Shape Memory Alloy (SMA) is a lightweight material with considerable higher actuation strain and work output than other active materials such as (high strain) piezo-materials. For this reason SMA-actuators have a great potential in micro-robotic systems, such as catheters. In this work, a non-linear physical model for SMA-actuators has been derived, characterized and validated. The model accurately describes macroscopic behavior of the material. By using a suitable class of transformation dynamics, parameters in the model are engineering-based and can be determined with standard material characterization tests. The model is more accurate than traditional models used for SMA control applications, without increased model complexity.

WeP04-4 **15.15–15.40**

Separation of breathing signals from respiratory response using regularization

Hannes Maes Vrije Universiteit Brussel
Gerd Vandersteen Vrije Universiteit Brussel

Lung diseases can be monitored by measurement of the respiratory admittance. The forced oscillation technique (FOT) is a widely used measurement technique to obtain respiratory admittance. The FOT applies small amplitude pressure oscillations (in the order of 0.1kPa) at the mouth of the patient. A resulting airflow generated by the patient as a response to the pressure oscillations is measured. The respiratory admittance G is defined as the frequency dependent ratio between the resulting air flow and the imposed pressure. A lot of useful information is contained in the frequency range of spontaneous breathing (0.1 - 1 Hz). Therefore, a setup is developed that can generate pressure oscillations in this frequency range. To make the measurement technique clinically practical for patients, the setup is designed so that the patient can continue breathing spontaneously during the measurement. This spontaneous breathing generates a signal in the same frequency range as the respiratory response. Since the setup does not allow to measure the breathing signal separately, the breathing signal is considered as a disturbance on the response signal. This work focuses on the separation of the breathing signal and the respiratory response in order to obtain the respiratory admittance.

WeP04-5 **15.40–16.05**

Estimating the BLA of MIMO sub-networks in simulations

Adam Cooman Vrije Universiteit Brussel
Ebrahim Louarroudi Vrije Universiteit Brussel
Gerd Vandersteen Vrije Universiteit Brussel

The estimation of the Best Linear Approximation of Multiple-Input Multiple-Output blocks in a complex network is considered. Classic techniques use extra small-signals, which can disturb the non-linear operating point. We show that linearisation of the network around the large-signal input has several advantages for the estimation.

WeP05 **Seaside**

Control Application II

Chair: Tom Oomen **Wednesday, 14.00–16.05**

WeP05-1 **14.00–14.25**

Optimal control of greenhouse climate with grower defined bounds

Peter van Beveren Wageningen UR
Jan Bontsema Wageningen UR
Gerrit van Straten Wageningen UR
Eldert van Henten

An optimization framework to minimize the total energy input to a greenhouse was developed and analyzed for a modern greenhouse with active cooling and industrial CO2 injection.

WeP05-2 **14.25–14.50**

Robust control of fuel-cell-car-based smart energy systems

Farid Alavi TU Delft
Bart De Schutter TU Delft

Any fuel cell car can also be considered as a small power plant that can produce electricity from hydrogen in an efficient and clean way. By considering a large number of fuel cell cars in the future, one can imagine the presence of several locations spread in the city that can provide a safe parking place for these kind of cars and at the same time, may extract electricity from the fuel cells of the cars and inject it into the power grid. Therefore, these kind of installations can be considered as future power plants.

The car as power plant (CaPP) can increase the efficiency of the electricity production. However, there are several challenges in the realization of such a system. Technological challenges, like efficient ways to produce hydrogen and fuel cells, social behavior of fuel cell car owners in presence of such a system, and charging/discharging management of the vehicles are among the most important challenges. In this project, we will develop a robust hybrid model-based predictive control (MPC) approach to determine the optimal time instants to charge or discharge the electrical vehicles in a CaPP installation in order to minimize the overall cost of the system.

WeP05-3 **14.50–15.15**

Cartesian constrained time-optimal point-to-point motion planning for robots: the waiter problem

Niels van Duijkeren KU Leuven
Frederik Debrouwere KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers

In this work methods are explored to solve the trajectory generation problem for robotic manipulators in application to the waiter problem. The waiter problem considers moving a non-fixed object time-optimally from an initial pose to a final pose while preventing the object to slide, lift or tip over, equivalently to a waiter that carries a tray with drinks. In previous work, a simplified version of the waiter problem is formulated as a convex optimization problem. Assuming a fixed geometric path, the optimal timing along this path is determined subject to the previously outlined limiting criteria. This convex problem can be solved efficiently, but is still conservative. Namely, appropriate tilting of the tray allows reduce the overall motion time. We present attempts to include the shape of the path in the optimization and to implement an efficient solution algorithm for this non-convex optimization problem.

WeP05-4 **15.15–15.40**

Counterweight synthesis for time-optimal robotic path following

Frederik Debrouwere KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers KU Leuven

Robot path following problems determine the motion of a robot along a predetermined geometric Cartesian end effector path without any preassigned timing information. Many problems in robotics can be cast as path following problems. The goal of this work is to explore the potential of adding counterweights to the robot structure in order to decrease the optimal motion time for path following problems. The idea is that the torque required to move the robot links is countered by the torque of the counterweight, hence the motor can use the ecces of torque to move the link faster. This idea originates from classic examples such as elevators. The problem of optimizing both counterweights and timing along the path can be cast as a non-convex optimization problem with bilinear inequality constraints. Despite the non-convexity of this problem, it can still be solved efficiently due to a proper problem formulation, rendering a relevant solution that can be used in practice.

WeP05-5 **15.40–16.05**

Approximate Bisimulation Relations for Linear Systems

Noorma Yulia Megawati Rijksuniversiteit Groningen
Arjan van der Schaft Rijksuniversiteit Groningen

In this paper we defined the notion of approximate bisimulation relation which allows the transfer functions which has some momen matching. The moment matching method are class of model reduction method which based on the notion of moment of a transfer function of linear system . The idea is to equalize a spesific number of the leading coefficients of the Laurent series expansion of the transfer function. We concentrated on Krylov method in particular Two-sided Lanczos method preserving the first 2k Markov parameters of the transfer function are the same

WeE01 **Les Arcades**

Games & Agents II

Chair: Bayu Jayawardhana **Wednesday, 16.30–18.35**

WeE01-1 **16.30–16.55**

Global asymptotic stability in multi-agent systems

Filip Koerts Rijksuniversiteit Groningen
A.J. van der Schaft Rijksuniversiteit Groningen
C. de Persis Rijksuniversiteit Groningen
M. Bürger

In linear multi-agent systems defined on a graph with agent defined on the nodes and controllers defined on the edges, we can partition the nodes into a set of damped and a set of undamped nodes. The steady-state solutions of this system can be analyzed by means of the kernel of an appropriate observability matrix. In the field of consensus dynamics, the question is whether the agents states will reach output agreement. This is the case is if and only if the system globally asymptotically stable (GAS). We present a sufficient condition for GAS merely based on topological properties. If the damped nodes form a so-called zero forcing set in the graph, the system is shown to be GAS.

WeE01-2 **16.55–17.20**

Predicting on-line opinion dynamics using consensus models

Corentin Vande Kerckhove Université catholique de Louvain
Samuel Martin Univ-Lorraine

The modern information and communication technologies provide a new potential to design systems able to harness collective intelligence. These social systems incorporate collective decision processes resulting from opinion dynamics. Yet, predicting opinion dynamics in the context of social influence largely remains an open problem. The present work provides a new step in this direction.

WeE01-3 **17.20–17.45**

Stability analysis for repeated snowdrift games

Pouria Ramazi Rijksuniversiteit Groningen
Ming Cao Rijksuniversiteit Groningen

We focus on a special class of anti-coordination evolutionary games, repeated snowdrift games, to carry out some rigorous stability analysis for the evolutionary dynamics for the competition of three typical decision-making strategies.

WeE01-4 **17.45–18.10**

Local mean field analysis of the Linear Threshold Model

Wilbert Samuel Rossi UTwente
Giacomo Como Lund University
Fabio Fagnani Politecnico di Torino

The spread of new behaviors may exhibit cascading effects in social, economic and technological networks. These phenomena generally depend on the topology of the network as well as the nature of the local agents dynamics. We consider the Linear Threshold Model on directed random graphs, whereby each agent activates (deactivates) when more (less) than a certain threshold of its neighbors are activated. We wish to approximate such dynamic and identify control heuristics. The locally tree-like structure of those large networks allows for an efficient approximation of the activation process in terms of a one-dimensional recursive equation, that describes the evolution of the expected fraction of active nodes on a infinite tree. We show that, for a generic instance of the network and initial condition, the behavior of the activation process on the original random network is close to the solution of such recursive equation, with probability converging to one exponentially fast in the network size. Similar results continue to hold in a variant of the model where the thresholds are dynamically adjusted, making the approach amenable to the design of control strategies.

WeE01-5 **18.10–18.35**

New Applications of Tensors to Graphs

Paul Smyth KU Leuven
Johan Suykens KU Leuven
Lieven De Lathauwer KU Leuven Kulak

The classical way to analyse graphs and networks is via an adjacency matrix capturing the connections between vertices. Tensors, multilinear extensions of matrices, can be used to capture different kinds of graph information, such as different kinds of connections between vertices or how the graph evolves in time. In this talk we will consider a different application of tensors to graphs, using the higher-order nature of tensors to capture higher-order information about connections between vertices. As a concrete example, we shall describe a particular tensorization of the adjacency matrix which captures connections between triples of vertices, i.e. triangles, and show how it can be used to identify clusters in real networks.

WeE02 — Mechanical Engineering II — Emanuel

Chair: Maarten Steinbuch **Wednesday, 16.30–18.35**

WeE02-1 **16.30–16.55**

Iterative Feedforward Control with Application to a Wafer Stage

L.L.G. Blanken TU Eindhoven
F.A.J. Boeren TU Eindhoven
D.J.H. Bruijnen Philips
T.A.E. Oomen

Feedforward control enables high servo performance in industrial motion systems. The key performance enhancement is in general obtained by using feedforward with respect to the reference trajectory. In existing methods, typically a trade-off exists between the attainable performance and the required robustness to changes in the reference. Through new developments in feedforward control it is aimed to attain high servo performance for a class of reference signals. To achieve this, measured data from previous tasks is exploited in conjunction with a suitable parametrization for the feedforward controller. Existing approaches focus on a polynomial parametrization. However, it is shown that for a rational system, a rational parametrization is required to attain high servo performance for a class of reference

signals. The presented research aims to introduce such a parametrization in iterative feedforward control using system identification techniques.

WeE02-2 **16.55–17.20**

Hybrid Potential Bacterial Foraging Optimization Algorithm with Robot Swarm Obstacle Avoidance

Thoa Mac Thi Ghent University
Cosmin Copot Ghent University
Robin De Keyser Ghent University
Trung Tran Duc

Bacterial foraging optimization is a heuristic algorithm inspired from foraging behavior based on swarm algorithms which have been successfully applied for optimization problems and robot swarm navigation [1]. A robot swarm is simply a group of robots that move in some cohesive way in order to perform some tasks. In moving from one position to another, robots must avoid certain obstacles that appear in their workspace. In this paper, we consider the hybrid potential bacterial foraging method to nd the optimal path for cooperative robot swarm. To solve this problem, the obstacle and goal functions are combined into a cost function. The swarm of robots is engaged in a social foraging by cost functions, which are viewed as a nutrient prole. The basic foraging strategy is made adaptive through a potential scheme in order to nd the global optimal solution.

WeE02-3 **17.20–17.45**

An experimental comparison of control architectures for bilateral teleoperation

Ruud Beerens TU Eindhoven
Dennis Heck TU Eindhoven
Henk Nijmeijer TU Eindhoven

Related to remote handling applications in nuclear fusion reactors, we present the development of a comparative analysis of different control strategies for bilateral teleoperation under the influence of communication delays, including clear representative performance metrics. We focus on several architectures that range from motion synchronization to a combination of motion and explicit force control. To this end, two series of experiments on a one degree of freedom teleoperation setup are designed to test and compare these architectures on motion synchronization, physical operator load, force reflection and stiffness perception. Our main conclusions are that the use of force sensors, especially at the slave side, is beneficial for force reflection and stiffness perception, especially for large values of the communication delay. For delays up to 10 ms, a four-channel controller performs best. For larger delays, using wave variables in combination with a four-channel controller results in the best overall performance. Moreover, position-based architectures are not recommended for large values of the delay due to poor motion tracking and high operator effort.

WeE02-4 **17.45–18.10**

A waterbed effect in disturbance feedforward control with application to a vibration isolator

Michiel A. Beijen TU Eindhoven
Marcel F. Heertjes TU Eindhoven
Hans Butler TU Eindhoven
Maarten Steinbuch

Disturbance feedforward control (DFC) is found in many applications, such as active noise/vibration control and stage synchronization. In this paper, the waterbed effect that exists for DFC systems is described. This waterbed effect represents a performance trade-off that exists for DFC systems, introduced by sensor dynamics and filtering, sampling delays and non-perfect plant inversion in the controller design. The waterbed effect is described by the feedforward sensitivity integral, which is similar to the Bode sensitivity integral known from feedback control systems. It follows that DFC systems have the performance properties of a feedback system, but the stability properties of a feedforward control system. As an illustrative example, DFC is added to an active vibration isolation setup. For this setup, both the predicted and experimental results illustrate the waterbed effect, in the sense that disturbance rejection at mid-frequencies leads to amplification at low and high frequencies. Further research focuses on developing a feedforward loop shaping method, taking into account the trade-off imposed by the waterbed effect.

WeE02-5 **18.10–18.35**

Iterative Learning Control for Varying Tasks

Jurgen van Zundert TU Eindhoven
Joost Bolder TU Eindhoven
Sjirk Koekebakker Océ Technologies
Tom Oomen

Iterative Learning Control (ILC) can significantly enhance the performance of systems that perform repeating tasks. However, small variations in the task often lead to a large performance deterioration. This leads to a trade-off between high performance and extrapolation properties, i.e., the ability to cope with reference variations. The goal of this research is to improve this trade-off in ILC.

WeE03 **Impresario**

Identification VI

Chair: John Lataire **Wednesday, 16.30–18.35**

WeE03-1 **16.30–16.55**

Woofer-tweeter adaptive optics for EUV lithography

Michel Habets TU Eindhoven
Ruben Merks TU Eindhoven
Siep Weiland TU Eindhoven
Wim Coene

In this work, we present an integrated opto-thermo-mechanical modeling approach for thermal aberration prediction and control in extreme ultraviolet lithography. The thermally induced wavefront aberrations are mitigated by means of a wavefront correction strategy, based on two compensators.

WeE03-2 **16.55–17.20**

RF identification and filter synthesis: a happy marriage?

Evi Van Nechel Vrije Universiteit Brussel
Yves Rolain Vrije Universiteit Brussel

Currently, lters at RF frequencies are designed using brute force optimization. The drawback hereof is the lack of physical insight in and sensitivity knowledge about the obtained design. On the other hand, classical lter synthesis methods fall short to accurately realize the transmission line based lters that are needed at RF frequencies. In this work, we will try to bridge the gap between these approaches. We propose a two-step procedure. First, a geometry dependent model set for an elementary transmission line structure is identied. This model allows for an improved realization of the lter. In a second phase, the model structure is incorporated in the approximation of the lter template. Hence, the lter synthesis becomes technology aware.

WeE03-3 **17.20–17.45**

Tensor-based reduced order adjoints for water flooding optimization

Edwin Insuasty TU Eindhoven
Paul Van den Hof TU Eindhoven
Siep Weiland TU Eindhoven
Jan Dirk Jansen

In this work, we compute gradient-based optimal production strategies for water flooding using reduced order adjoints. The projection spaces are computed by applying tensor decompositions to spatial-temporal data from multiphase flow simulations, represented in the form of multidimensional arrays. Then, the adjoint equations are projected onto a reduced order tensor-based projection space, reducing the computational effort of evaluating gradients used in the optimization routine to maximize the profits of the production stage.

WeE03-4 **17.45–18.10**

Identifying a Multi-tapped Lossless Transmission Line

Maral Zyari Vrije Universiteit Brussel
Yves Rolain Vrije Universiteit Brussel

The goal of this work is to model a transmission line that is tapped by lumped impedances, where only the input

and the output of the lines are accessible. A model is introduced that make it possible to localize the reflections that are caused by the lumped elements in the system.

WeE03-5 **18.10–18.35**

Two different approaches to dynamic modeling of hot-melt extrusion processes

Jonathan Grimard UMons
Laurent Dewasme UMons
Alain Vande Wouwer UMons

Hot melt extrusion is a complex process becoming more and more popular in pharmaceuticals and involving a multitude of interacting physico-chemical phenomena, making its mathematical modeling tedious. The extruded material is indeed subject to the laws of fluid mechanics, heat exchanges and the evolution of its rheological properties. In this work, two alternative modeling approaches are proposed. The first is based on a representation of the system by setting a series of ideal well-mixed reactors in order to reproduce the dynamics of a real extruder by choosing the right number of ideal reactors. The second modeling approach is based on partial differential equation techniques describing more physically the phenomena occurring in a twin-screw extruder. This work will be divided in two parts, one describing the development of the two modeling structures and the other one discussing each method performances through a comparative study.

WeE04 **Bloemen**

LPV

Chair: Rik Pintelon **Wednesday, 16.30–18.35**

WeE04-1 **16.30–16.55**

Identification of a static LPV differential equation in the continuous time and frequency domain

Jan Goos Vrije Universiteit Brussel
John Lataire Vrije Universiteit Brussel
Rik Pintelon Vrije Universiteit Brussel

We are studying the class of Linear Parameter-Varying (LPV) systems, which is closely related to the class of Linear Time-Varying (LTV) systems. The difference is that the model dynamics depend on an external signal p(t) (which we assume to be known), instead of having an unknown dependency on the (continuous) time t. Specifically, we present an identification technique for the estimation of Linear Parameter-Varying (LPV) differential equations.

WeE04-2 **16.55–17.20**

Parametric estimation of LPV partial differential equation

Julien Schorsch Université Libre de Bruxelles

This paper presents some methods for linear parameter varying identifying partial differential equation models. The proposed methods are the conventional iterative least-squares and the refined instrumental variable-based technique. Monte Carlo simulation analysis results are presented to illustrate the effectiveness the proposed methods.

WeE04-3 **17.20–17.45**

Estimation of LPV-SS Models with Static Dependency

P. B. Cox TU Eindhoven
R. Tóth TU Eindhoven
P. M. J. Van den Hof TU Eindhoven

Numerous physical or chemical processes exhibit parameter variations due to non-stationary or nonlinear behaviour, often depending on measurable exogenous variables or measurable endogenous process states. These parameter variations can be captured in the linear parameter-varying (LPV) modeling paradigm. For control purposes, LPV state-space (SS) models are preferable, particularly with static and affine dependence on the scheduling signal. To tackle the computational complexity and perform rapid identification of LPV-SS models, a three-step approach is presented. The three steps are: 1) the estimation of the impulse response coefficients, also known as Markov coefficients, 2) an exact LPV-SS realization scheme based on these estimated Markov coefficients, and 3) an LPV-SS nonlinear optimization based refinement step. In the first step we present two possible methods: i) correlation analysis and ii) MIMO finite impulse response estimation with ridge regularization. The second step is a basis reduced, deterministic Ho-Kalman like LPV-SS realization scheme, which uses the estimated Markov coefficients of the first step. Finally, a third step

is executed as a refinement step to reach the maximum likelihood estimate, for which two methods are considered i) an iterative LPV-SS expectation-maximization method and ii) an extension of the enhanced Gauss-Newton method.

WeE04-4 **17.45–18.10**

A combined global and local identification approach for LPV systems

Dora Turk KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers KU Leuven

This paper is focused on exploring the possibility of combining global and local approach for identification of linear parameter-varying (LPV) systems. The nonlinear least-squares identification framework for LPV systems is considered, convenient for several reasons: it easily combines data originating from different experiments, the data it engages can be in the time and/or the frequency domain, it allows to emphasize particular experiments by simply employing weighting matrices, and the solution can be efficiently found by the well-known Levenberg-Marquardt algorithm. In this way, it is possible to balance between the importance of the system's behavior under changing scheduling parameter conditions, and the behavior for fixed operating conditions.

WeE04-5 **18.10–18.35**

Description of the cyclostationary processes in Linear Periodically Time-Varying (LPTV) systems

Vladimir Lazov Vrije Universiteit Brussel
Ebrahim Louarroudi Vrije Universiteit Brussel
Gerd Vandersteen Vrije Universiteit Brussel

Cyclostationary (CS) processes are much more than a trivial variation of stationary processes. Cyclostationarity can generally be exploited to enhance the accuracy and reliability of information collected from data sets such as measurements of corrupted signals. In communication systems, the statistical parameters of signals usually vary periodically with time. Our goal is to grow the awareness by recognizing and exploiting CS in the design and modeling process rather than ignoring it by treating signals as if they were stationary.

WeE05 **Seaside**

Nonlinear Control

Chair: Joseph Winkin **Wednesday, 16.30–18.35**

WeE05-1 **16.30–16.55**

Time-Delay Pre-Filter Design for Periodic Signal Tracking of Lightly-Damped Multivariable Systems

Rick van der Maas TU Eindhoven
Tarunraj Singh University at Buffalo

Modern trends in mechatronic positioning systems require faster movements and increased accuracy. Lightweight system design is motivated by the desire to achieve higher accelerations, but this is at the cost of a shift of flexible dynamical behavior to a lower frequency region. Dealing with the imposed contradiction typically requires advanced control strategies. Input-shaping or time-delay filtering (TDF), are proven methods for the reduction of undesired motion induced dynamical effects, however typically limited to point-to-point motions. A method is proposed in this work that enables zero-phase error tracking for periodic signals. Extensions are available for multivariable systems and increased robustness for variations in model parameters and forcing frequencies.

WeE05-2 **16.55–17.20**

Output agreement problem with unmatched disturbances

Nima Monshizadeh Rijksuniversiteit Groningen
Claudio De Persis Rijksuniversiteit Groningen

Output agreement has evolved as one of the most important control objectives in cooperative control. Output agreement roughly means that agents agree on a certain quantity of interest. This is typically done through communications via an interconnection structure given by a graph. In this talk, we consider agents with non-indentical nonlinear port-Hamiltonian dynamics. The edge dynamics is assumed to be single integrator, yet with a nonlinear output map. Our objective is to achieve output agreement on a prescribed set point, and despite the presence of constant disturbances which are affecting the nodal dynamics. The key contribution of our results is that we investigate the "unmatched

control-disturbance" scheme, meaning that control signals and disturbances may be applied to different subset of nodes. An application of our results is balancing demand and supply in heterogenous power networks, where power generated at synchronous generators corresponds to the control inputs, and power demand at loads corresponds to disturbances.

WeE05-3 **17.20–17.45**

Asynchronous event-triggered implementation with a lower bound for global event intervals

Anqi Fu TU Delft
Manuel Mazo Jr. TU Delft

Following a recently proposed asynchronous event-triggered implementation, we propose an updated strategy that guarantees the lower bound of the event intervals between different sensors. This approach can avoid high instantaneous bit-rate.

WeE05-4 **17.45–18.10**

Energy Dissipation in Preisach and Duhem Hysteresis Models for Damage Estimation

J.J. Barradas-Berglind Aalborg University
B. Jayawardhana Rijksuniversiteit Groningen
R. Wisniewski Aalborg University

In this work we relate the variations of certain Preisach hysteresis operator to its dissipated energy, which is of particular interest since the former has been shown to be equivalent to the accumulated damage or fatigue based on the rainflow counting (RFC) method. Furthermore, based on the previous equivalent relations we propose a model predictive control (MPC) based strategy, where the minimization of the accumulated damage is achieved by incorporating the dissipated energy in the problem formulation. Due to the infinite dimensional characteristic of the Preisach hysteresis, we adopt the dissipated energy of the Duhem hysteresis, since it can be explicitly written as differential equation.

WeE05-5 **18.10–18.35**

Distributed control design for nonlinear output agreement in convergent systems

Erik Weitenberg Rijksuniversiteit Groningen
Claudio De Persis Rijksuniversiteit Groningen

This work studies the problem of output agreement in homogeneous networks of nonlinear dynamical systems under time-varying disturbances using controllers placed at the nodes of the networks. For the class of contractive systems, necessary and sufficient conditions for output agreement are derived, and these conditions relate the eigenvalues of the network Laplacian and the node dynamics.

ThM01 **Les Arcades**

Games & Agents III

Chair: Paolo Frasca **Thursday, 09.00–11.05**

ThM01-1 **09.00–09.25**

Constrained proportional integral control of dynamical distribution networks with state constraints

Jieqiang Wei Rijksuniversiteit Groningen
Arjan van der Schaft Rijksuniversiteit Groningen

In this paper we continue the study of the dynamics of the distribution network. Identifying the network with a directed graph we associate with every vertex of the graph a state variable corresponding to storage, and with every edge a control input variable corresponding to flow. In previous study we proved that distributed PI controller can achieve output agreement for this type of system. Here we will modify the distributed PI controller to have the output agreement with some state constraints.

ThM01-2 **09.25–09.50**

Average consensus over unreliable networks: an improved compensation method

Francesco Acciani UTwente
Geert Heijenk UTwente
Paolo Frasca UTwente

We consider in the present work the average consensus problem over fully connected networks, with transmitter-based stochastic communication losses. A solution to achieve convergence to the exact average value of the initial states is presented.

ThM01-3 **09.50–10.15**

Properties of feedback Nash equilibria in scalar LQ differential games

J.C. Engwerda Tilburg University

In this note we study linear feedback Nash equilibria of the scalar linear quadratic N-player differential game. We present a complete characterization of the solution structure of this game using a geometric approach. Furthermore we investigate the effect on this solution structure of some characteristics of the game, i.e.: the number of players; the entrance of new players; and the level of asymmetry. For that purpose we distinguish three types of the game: the economic game; the regulator game and the mixed game. The analysis is restricted to the case the involved cost depend only on the output and control variables.

ThM01-4 **10.15–10.40**

Consensus and Automata

Pierre-Yves Chevalier Université catholique de Louvain
Julien Hendrickx Université catholique de Louvain
Raphaël Jungers Université catholique de Louvain

We study discrete-time consensus systems using results from automata theory. We have a set of stochastic matrices, each one representing an averaging process over a communication network. The dynamics switches between these transition matrices. We wonder whether there is a sequence of matrices such that the system converges to a state of consensus. We prove that this question can be answered in polynomial time in the number of agents. We also prove that there exists a periodic such sequence with period shorter than n^3 and we prove that finding the sequence with the shortest period is an NP-hard problem.

ThM01-5 **10.40–11.05**

Robustness Issues with Directed Formations

Hector Garcia de Marina Rijksuniversiteit Groningen
Miguel Martinez University of Alcala
Ming Cao Rijksuniversiteit Groningen
Bayu Jayawardhana

Recently some robustness issues on formation control based on the gradient of potential energy have been identified. These issues have been studied for rigid formations where the underlying graph describing the sensing topology is undirected. More specifically, the gradient-based controllers are not robust when a pair of neighboring robots measure

differently about the relative position between each other. The effects of this discrepancy for formations in the plane are a distortion of the final shape of the formation with respect to the desired one and an undesired circular motion of the agents. In this work we turn our attention to the formations where the sensing topology is directed. Therefore by construction there cannot exist discrepancies in the measured relative positions between neighbors since only one agent of any neighboring pair is measuring, but the effects of having a distorted shape and an undesired motion of the agents show up again when we discretize the dynamics of the agents and add zero-mean noise to the sensor readings. The surprise comes when one should expect a randomly perturbed movement of the formation due to the random noise in the measurement, but we will show that for the directed triangular formation, the dominating undesired movement is in fact a circular one whose mean angular velocity can be calculated. This effect can also be extrapolated to bigger directed rigid formations consisting of more than three agents

ThM02 **Emanuel**

ILC & Adaptive Control

Chair: Jan Swevers **Thursday, 09.00–11.05**

ThM02-1 **09.00–09.25**

Model Inversion-based Iterative Learning Control: Optimal Performance Trade-offs

Tong Duy Son KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers KU Leuven

Iterative learning control (ILC) is widely used in control applications to improve performance of repetitive processes. The key idea of ILC is to update the control signal iteratively based on measured data from previous trials, such that the output converges to the given reference trajectory. Model-inversion based ILC uses the system model as a basis for the learning algorithm. Since system models are never perfect in practice, accounting for model uncertainty in the model inversion-based ILC analyses and designs needs to be addressed. This work first discusses the robust monotonic convergence and tracking performance conditions of model inversion-based ILC. Next, the learning gain $\{Q\}$ is designed such that the corresponding ILC controller realizes an optimal trade-off between the converged tracking performance and the convergence speed. The design is reformulated as a convex optimization problem. Finally, the proposed model-inversion based ILC design is validated through a numerical example.

ThM02-2 **09.25–09.50**

Optimal Control of Uncertain Switched Systems Based on Model Reference Adaptive Control

Shuai Yuan TU Delft
Simone Baldi TU Delft
Bart De Schutter TU Delft

Switched systems are an important subclass of hybrid systems that consists of subsystems with continuous dynamics and a rule to regulate the switching behavior between them. Switched systems appear in a wide range of applications, such as intelligent transportation systems and smart energy systems. we propose to adopt a model reference adaptive control (MRAC) scheme to solve optimal control problems of uncertain LTI switched systems.

ThM02-3 **09.50–10.15**

An Adaptive Online Game-theoretic Approach for Complete Vehicle Energy Management

H. Chen TU Eindhoven
J.T.B.A. Kessels TU Eindhoven
S. Weiland TU Eindhoven

Complete Vehicle Energy Management (CVEM) is proposed recently. A single-leader multi-follower game-theoretic framework has been developed for CVEM. In this approach, the likelihood of driving behaviour is characterized by a probability distribution function, G, in terms of the requested torque and speed over a drive-cycle. Up to now, using one G function in the game-theoretic setting has been explored. On the other hand, it should be noted that G functions may vary significantly for different drive-cycles and drivers. Consequently, the use of only one G function in the optimization criterion for an energy management system may not produce robust results when varying over different drive-cycles and different drivers. In this paper, the possibility of adapting the game-theoretic approach to improve the robustness over different drive-cycles is explored.

ThM02-4 **10.15–10.40**

Wave form replication using combined Adaptive and Iterative Learning Control

Sikandar Moten KU Leuven
Goele Pipeleers KU Leuven
Jan Swevers KU Leuven
Wim Desmet

In the automotive industry, durability testing is a crucial step in the design and development cycle. The goal of these tests is to replicate or track real operating conditions in lab environment typically on a multi-axis vibration test rig. The wave forms that have to be tracked are repeated sequentially for a certain number of cycles or until failure occurs. Existing techniques to replicate these sequences consist of fixed position controllers for the actuators with feedforward approaches; for instance the current state of the art Time Wave Replication (TWR) process. The TWR process consists of two phases: Identification of non-parametric frequency domain model and its inverse followed by off-line iterative learning control (ILC) phase. Although TWR is a slow off-line process for finding the appropriate drive signals, it allows to control systems with delays and non-minimum phase, which is typical for hydraulic test rigs. This research proposes an online technique that can also handle systems with delays and non-minimum phase by investigating a combined use of adaptive inverse control (AIC) and ILC . As a result, this will help to accelerate the drive signal generation process.

ThM02-5 **10.40–11.05**

Combustion Control with Multiple Fuel Injections for Clean and Fuel Efficient Diesel Engines

Xi Luo TU Eindhoven
Frank Willems TU Eindhoven

The combustion phase and load for diesel engines may differ from the optimal one due to practical disturbances, such as the change of ambient conditions, fuel quality and engine component ageing. This deviation downgrades diesel engines performance, including higher fuel consumption and engine-out emission level. A feedback controller at the combustion level can be designed to manipulate the timing of each fuel injection pulse such that the optimal engine performance is achieved with the presence of various disturbances. Several metrics are extracted from the cylinder pressure signal and used as the feedback signal that describes the combustion. Given the reference value of these combustion phase and load metrics, which leads to optimal engine performance, the difference between the reference and the feedback signal is used to update the fuel injection timing parameters for the next combustion cycle. Judging from the simulation results where the two-pulses fuel injection profile is adopted, the measured combustion phase metrics, as well as the engine performance, converge to the nominal values rapidly with the presence of disturbances. Therefore, it can be concluded that the designed controller manages to reject the disturbances at stationary operation condition such that the engine performance becomes robust.

ThM03 **Impresario**

Identification VII

Chair: Amélie Chevalier **Thursday, 09.00–11.05**

ThM03-1 **09.00–09.25**

Initial estimates for Wiener-Hammerstein dynamics using phase-coupled multisines

Koen Tiels Vrije Universiteit Brussel
Maarten Schoukens Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel

Even if nonlinear distortions are often present, many dynamical systems can be approximated by a linear model. When the nonlinear distortions are too large, however, a linear model is insufficient, and a nonlinear model is needed. One possibility is to use block-oriented models. These models consist of linear dynamic (L) and nonlinear static (N) sub-blocks. We propose a simple initialization method for a Wiener-Hammerstein model (LNL cascade). The product of the transfer functions of the two linear blocks can be easily obtained via the best linear approximation (BLA) of the system for a Gaussian excitation. Splitting the global dynamics over the individual blocks turns out to be more difficult. We propose a well-designed multisine excitation and a modified BLA on a shifted frequency grid. The input dynamics are shown to shift with a frequency offset that can be chosen by the user, while the output dynamics do not shift. This allows us to separate the two linear blocks via a simple initialization method, based on a linear system identification step. Experimental results obtained from the Wiener-Hammerstein benchmark system illustrate the good performance of the method.

ThM03-2 **09.25–09.50**

Dynamic berth and quay crane allocation for complex berthing process in container terminals

R. T. Cahyono Rijksuniversiteit Groningen
E. J. Flonk Rijksuniversiteit Groningen
B. Jayawardhana Rijksuniversiteit Groningen

We study a dynamic berth and quay cranes allocation strategy in general seaport container terminals. We develop a dynamical model that describes the operation of berthing process with multiple discrete berthing positions and multiple quay cranes. Based on the proposed model, we develop a dynamic allocation strategy using the model predictive control (MPC) paradigm. The proposed strategy is evaluated using real data from a container terminal in Indonesia. The simulation results show that the MPC-based allocation strategy can improve the efficiency of the process where the total handling and waiting cost is reduced by approximately 20% in comparison to the commonly adapted method of first-come first-served (FCFS) (for the berthing process) combined with the density-based quay cranes allocation strategy.

ThM03-3 **09.50–10.15**

Filter interpretation of the cost function in regularized FIR modeling

Anna Marconato Vrije Universiteit Brussel
Johan Schoukens Vrije Universiteit Brussel

We consider the estimation of FIR models by means of Bayesian regularization techniques. The regularization approach allows one to obtain solutions characterized by a reduced variance, at the price of slightly increasing the bias term. This is done by embedding in the problem prior information about the underlying linear dynamic system, by designing a suitable kernel matrix. In this work, we look at the same problem from a different perspective, focusing on the cost function interpretation, rather than on the kernel denition.

ThM03-4 **10.15–10.40**

Towards an assistive drug delivery system for general anesthesia

Dana Copot Ghent University
Clara Ionescu Ghent University
Robin De Keyser Ghent University

General anesthesia plays an important role in surgery and intensive care unit (ICU) and requires critical assessment of induced quantities of drugs into the patient [1]. It is characterized by unconsciousness through the action of anesthetics, but also by loss of the ability to perceive pain through the action of analgesics. Analgesia is a key feature of general anesthesia, but there is no available sensor to measure pain relief during general anesthesia. Therefore, in clinical practice, the anesthesiologist has to provide specific care during surgery for neuromuscular blockade, hypnosis and analgesia.

ThM03-5 **10.40–11.05**

Nonconvex Sorted l1 Minimization for Compressed Sensing

Xiaolin Huang KU Leuven
Lei Shi Fudan University
Johan A.K. Suykens KU Leuven

As an efficient convex relaxation for the 0 minimization, the l1 norm has been widely and successfully applied. For problems with fewer samplings, one needs to enhance the sparsity via non-convex methods, e.g., the iteratively reweighted l1 minimization. It assigns large weights on small components in magnitude and small weights on large components in magnitude, which enhances sparsity but brings nonconvexity. In this study, we consider a new kind of nonconvex penalties, of which the weights are set based on sorting the magnitude. On the one hand, the sorted l1-norm can enhance the sparsity, due to its non-convexity, and on the other hand it enjoys good convergence behavior, due to its piecewise convexity. Accordingly, we established iteratively reweighted method and iterative sorted thresholding and then prove the convergence to a local optimum. In numerical experiments, the sorted 1-norm shows better performance in sparse signal recovery than weighting methods based on component values.

ThM04 **Bloemen**

Systems Theory II

Chair: Geert Gins **Thursday, 09.00–11.05**

ThM04-1 **09.00–09.25**

Cayley-Hamilton and Hilbert's function for nD systems theory

Antoine Vandermeersch KU Leuven
Bart De Moor KU Leuven

Similar to the 1D case, there is a strong link between computational algebra and nD realization theory. In 1D realization theory, the link is symbolized using the Cayley-Hamilton theorem. In nD systems theory, systems of multivariate polynomials now form the natural extension that allow us to model nD systems. We utilize a linear algebra framework to establish model orders based on rank properties of large structured matrices that involve the equation coefficients. We provide an intuitive definition of the Cayley-Hamilton theorem for nD systems and illustrate its role in nD realization algorithms. Finally, we show how this Cayley-Hamilton theorem is closely intertwined to the transition from Hilbert function to Hilbert polynomial through the index of regularity in the algebra setting.

ThM04-2 **09.25–09.50**

Economic impact of sensor and actuator degradation in offices using model based heating and cooling control

Joachim Verhelst KU Leuven
Geert Van Ham KU Leuven
Dirk Saelens KU Leuven
Lieve Helsen

In this paper, the economic effects of degradation faults on the control performance of multiple model-based controllers are investigated through monte-carlo simulations over a reference year, using an emulator model of a hydronically heated and cooled office. Three controllers are compared, both in fault free and fault present periods, together with their lower and upper performance bound. The simulation results are summarized in graphical overviews per degradation type and subsequently discussed.

ThM04-3 **09.50–10.15**

Controllability and input selection for interconnected systems: a graph theoretic point of view

Jacob van der Woude TU Delft

In the nowadays society interconnected systems play an important role. For instance, think of complex networks as the internet and the social media, interconnected computer networks, but also networks of chemical or biological processes, and so on. Clearly, the ability to influence or control of such networks is an issue of great importance. The structured systems in this talk are a special kind of network systems based on linear difference or differential equations with constant coefficients in which the interconnection structure can be exploited. For structured systems statements concerning properties like connectability, controllability, observability, etc. can be derived from the interconnection structure. In this talk we want to discuss the problem of making an autonomous structured system, i.e., a system without input vertices, generically controllable by adding a number of input vertices. Questions that will be addressed are where to put these input vertices, of what type do they have to be (one input to one state vertex, one input to many state vertices,.. .), what is their minimal number, and so on.

ThM04-4 **10.15–10.40**

Stability analysis of switching systems with constrained switching sequences

Matthew Philippe Université catholique de Louvain
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We present a stability analysis framework for the general class of discrete-time linear switching systems for which the switching sequences belong to a regular language. First, we introduce a general class of multiple Lyapunov functions for these systems. They associate a different norm per node of a finite-automaton defining admissible the switching sequences. We show that the existence of such Lyapunov functions is necessary and sufficient for stability. Second, we present an estimation scheme for the exponential growth rate of these system. The method is based on quadratic approximations of the norms in the Lyapunov functions, and allows for an arbitrary accurate estimation in finite time (with known complexity). Last, we will present a sufficient condition for the boundedness of a system's trajectories (i.e. a condition for marginal stability). The condition is an extension of concept of irreducibility for constrained

switching systems.

ThM04-5 **10.40–11.05**

A geometric approach to fault detection and isolation for a class of bimodal piecewise-linear systems

A.R.F. Everts Rijksuniversiteit Groningen
P. Rapisarda University of Southampton
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In this work we study the fault detection and isolation problem for continuous bimodal piecewise-linear systems. Geometric techniques are used to design observers that generate residual signals which detect and identify faults.

ThM05 **Seaside**

Control II

Chair: Julian Stoev **Thursday, 09.00–11.05**

ThM05-1 **09.00–09.25**

State feedback control for systems pre-compensated by input shapers

Dan Pilbauer KU Leuven
Wim Michiels KU Leuven
Tomas Vyhlidal CVUT Prague

The main objective is to investigate the applicability of spectral methods for designing feedback controllers for systems which include an input shaper with time delays. The primary objective of including such a shaper into a feedback loop is to pre-compensate the low-damped oscillatory modes of a flexible subsystem, which is attached to the controlled main body of the system. For the spectral design of the controller, we adopt the recently proposed direct optimization approach for interconnected time delay systems and minimize the spectral abscissa of the closed-loop system. The presented methods are tested on a case study example, which is a multi-degree of freedom mechanical system.

ThM05-2 **09.25–09.50**

Positive stabilization of a discretized diffusion system

Jonathan N. Dehaye UNamur
Joseph J. Winkin UNamur

For unstable positive finite-difference systems approximating a diffusion PDE system with Neumann boundary conditions and scalar boundary input, parameterizations of all positively stabilizing state feedbacks are derived.

ThM05-3 **09.50–10.15**

Fault classification in batch processes: contribution plots versus process data

S. Wuyts KU Leuven
G. Gins KU Leuven
J.F.M. Van Impe KU Leuven
P. Van den Kerkhof

In statistical process monitoring, experts and operators generally diagnose abnormal situations using contribution plots. However, the contribution plots are subject to the so-called fault smearing effect which possibly masks the root cause of the upset and hence degrades performance of fault classification. Therefore, it is investigated whether automatic fault classification based on contribution plots can be replaced and improved by automatic classification based on raw or pretreated process data. As a case study, both approaches (i.e., using either sensor measurements or the contributions as input for automatic classification) are tested on simulated datasets representing the benchmark penicillin fermentation process Pensim, implemented in RAYMOND. For each approach, classification performance is maximized incrementally by proposing various manipulations of both sensor data and variables contributions based on the characteristics of the occurring faults. These pretreatments are of major importance for the performance of the automatic classification models. The main conclusion is that higher automatic classification performance is achievable using pretreated process data rather than variables contributions as model inputs, due to the negative influence of the fault smearing effect.

ThM05-4 **10.15–10.40**

Dynamic Event-triggered Control: Guaranteed Lp-gain Performance and Zeno-freeness

Victor Dolk TU Eindhoven
Niek Borgers TU Eindhoven
Maurice Heemels TU Eindhoven

In this work, a novel dynamic event-triggered control (ETC) strategy for state-feedback systems is proposed that can simultaneously guarantee a finite Lp-gain from disturbance to output and a strictly positive lower bound on the inter-event times (implying Zeno-freeness). The developed theory leads to tradeoff curves between (minimum and average) inter-event times and Lp-gains that depend on the selected medium access protocol.

ThM05-5 **10.40–11.05**

Distributed Sensor Fault Detection and Isolation over Sensor Network

Jingjing Hao Université Libre de Bruxelles
Michel Kinnaert Université Libre de Bruxelles

In order to provide reliable measurements, one should make sure that the measurements are fault free before using the measurements recorded by the wireless sensor network. The aim of this work is to design and implement distributed monitoring algorithm requiring limited computational resources while being robust with respect to environmental and operational changes.

Plenary: P3 **Les Arcades**

System identification in dynamic networks
Paul M.J. Van den Hof

Chair: Ivan Markovsky **Thursday, 11.30–12.30**

In current day systems and control research, as well as in technology development, distributed (control) systems play an important role. The systems to be controlled are no longer characterized by a single or multiple control loop, but a network structure underlies the dynamical interaction between several subsystems. In system identification the classical configuration is to consider open-loop or closed-loop systems. In this work we are going to explore the extensions of these configurations towards linear dynamic network structures, and we will discuss the several questions that this step yields. We generalize the classical closed-loop identification methods to deal with identification problems of particular modules in a network, and use tools from graph theory to verify the structural conditions. We discuss options of input/sensor selection, and assess the problems of introducing measurement noise in measured variables, handling the so-called errors-in-variables problem. In a dynamic network setting this latter problem will appear to be more easily solvable than in the classical closed-loop configuration. Finally we discuss options for identifying the structure/topology of a dynamic network.

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Organizational Comments

Welcome

The Organizing Committee has the pleasure of welcoming you to the *34th Benelux Meeting on Systems and Control*, at Center Parcs De Vossemeren in Lommel, Belgium.

Aim

The aim of the Benelux Meeting is to promote research activities and to enhance cooperation between researchers in Systems and Control. This is the thirty-fourth in a series of annual conferences that are held alternately in Belgium and The Netherlands.

Scientific Program Overview

1. Plenary lecture by *Tore Hägglund* (Lund University, Sweden) on **PID: Past, present and perspectives**.
2. Plenary lecture by *Achim Kienle* (Max Planck Institute for Dynamics of Complex Technical Systems, Germany) on **Dynamics and control of particulate processes**.
3. Plenary lecture by *Paul Van den Hof* (Eindhoven University of Technology, The Netherlands) on **System identification in dynamic networks**.
4. Contributed short lectures. See the list of sessions for the titles and authors of these lectures.
5. Meet-the-Experts sessions, providing an informal atmosphere where early-stage PhD students can interact with experts who will give their undivided attention for research advice and networking.

Directions for speakers

For a contributed lecture, the available time is 25 minutes. Please leave a few minutes for discussion and room changes, and adhere to the indicated schedule. In each room beamers are available. *When using a beamer, you have to provide a notebook yourself and you have to start your lecture with the notebook up and running and the external video port switched on.*

Registration

The Benelux Meeting registration desk, located in the foyer of the business center, will be open on Tuesday, March 24, from 09:00 to 12:30. Late registrations can be made at the Benelux Meeting registration desk, when space is still available. The on-site fee schedule is:

Arrangement	Price (EUR)
hotel room	580
2-room cottage	550
3-room cottage	520
meals only	500
one day	350

The registration fees include:

- Admission to all sessions.
- A copy of the Conference Booklet.
- Coffee, tea and water during the breaks.
- In the case of a three days arrangement: lunch and dinner on Tuesday; breakfast, lunch, and dinner on Wednesday; and breakfast and lunch on Thursday.
- In the case of a one day arrangement: lunch and dinner on Tuesday or Wednesday, or lunch on Thursday.
- Free use of a wireless internet connection (WiFi) in each cottage.

The registration fee does *not* include:

- Cost of phone calls
- Special ordered drinks during breakfast, lunch, dinner, in the evening, etc.

Organization

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Sponsor

The meeting is supported by the Research Foundation Flanders (FWO).

Conference location

The lecture rooms of Center Parcs De Vossemeren are situated on the ground floor. Consult the map at the end of this booklet to locate rooms. During the breaks, coffee and tea will be served in the foyer. Announcements and personal messages will be posted near the main conference room. Accommodation is provided in the conference center and in the cottages. Room/Cottage keys can be picked up at lunch time on the first day and need to be returned before 10:00 on the day of departure. Parking is free of charge.

The address of Center Parcs De Vossemeren is

Elzen 145
3920 Lommel
Belgium
T +32 (0)11 54 82 00

Facilities

The facilities at the center include a restaurant, bar, and recreation/sports facilities. You can refer to the reception desk of the center for detailed information about the use of these facilities.

Breakfast will be served in the "Evergreenz Restaurant", from 7:00 until 9:00. Lunches take place in the "Evergreenz Restaurant", from 12:30 until 14:00. The dinner on Tuesday takes place in the "Evergreenz Restaurant", from 19:00 until 21:00. The dinner on Wednesday takes place in the "Fuego Restaurant", from 19:00 until 21:00.

Best junior presentation award

Continuing a tradition that started in 1996, the 34^{th} Benelux Meeting will close with the announcement of the winner of the Best Junior Presentation Award. This award is given for the best presentation, given by a junior researcher, and it consists of a trophy that may be kept for one year and a certificate. The award is specifically given for quality of presentation rather than quality of research, which is judged in a different way. At the meeting, the chairs of sessions will ask three volunteers in the audience to fill out an evaluation form. After the session, the evaluation forms will be collected by the Prize Commissioners who will then compute a ranking. The winner will be announced on Thursday, March 26, in room Les Arcades, at 14:20. The winner is the candidate with the highest evaluation score among all candidates present at the prize ceremony. He or she will be presented the award, which consists of a trophy that may be kept for one year, and also a certificate. He or she will give the winning presentation once more at the end of the ceremony. The evaluation forms of each presentation will be returned to the junior researcher who gave the presentation. The Prize Commissioners are Jean-Charles Delvenne (Université catholique de Louvain), Paolo Frasca (University of Twente) and John Lataire (Vrije Universiteit Brussel).

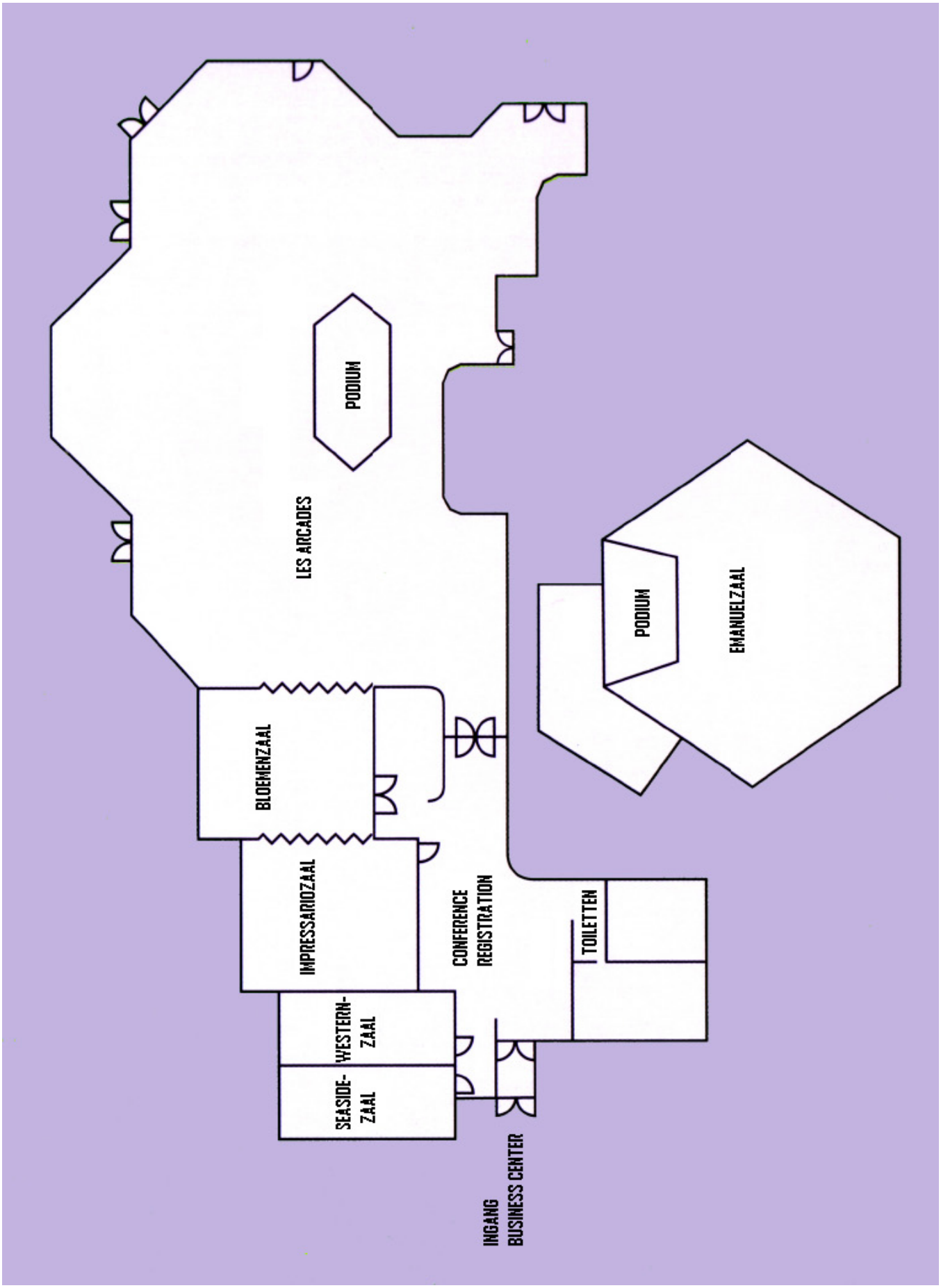
The organizing committee counts on the cooperation of the participants to make this contest a success.

DISC certificates and best thesis award

The ceremony for the distribution of the DISC certificates and for the Best Thesis Award will be held on Thursday, March 26, room Les Arcades, 14:00–14:20.

Website

An *electronic version* of the Book of Abstracts can be downloaded from the Benelux Meeting web site.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