# Final Program and Book of Abstracts

# nDS 09

## 6th International Workshop on Multidimensional (nd) Systems

Aristotle University of Thessaloniki

ΥΠΟΥΡΓΕΙΟ ΕΘΝΙΚΗΣ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ

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Abstracts and Program

# nDS 2009

## 2009 International Workshop on Multidimensional (nD) Systems

Aristotle University of Thessaloniki

Thessaloniki, Greece

June 29 - July 1, 2009

http://www.nds09.org

# Welcome to nDS 2009

It is our great pleasure to welcome you to the 6th International Workshop on Multidimensional (nD) Systems (nDS2009). Following the previous five editions (Lagów 1998, Czocha 2000, Notre Dame 2002, Wuppertal 2005, Aveiro 2007), nDS2009 is held in Thessaloniki, Greece, from June 29 to July 1, 2009.

The main goal of the nDS workshops is to present the current state of the art in the theory and applications of multidimensional systems as well as to enable active researchers in the area of nD systems to meet and exchange ideas.

In this edition, the scientific program includes three invited talks:

**Paula Rocha**
***Stabilization of nD behaviors***

**Anton Kummert**
***Fundamentals and Application Results for Multidimensional Circuits***

**Danwei Wang**
***Extension of Learnable Bandwidth for Iterative Learning Control***

and 27 contributed talks, divided into seven sessions:

- **Multidimensional Systems (two sessions)**
- **Multidimensional Signal Processing (one session)**
- **Repetitive Processes (two sessions)**
- **Multidimensional Systems Related To Operator Algebras, Operator Theory and Stochastics (two invited sessions)**

The workshop has received the support of the:

- Department of Mathematics of the Aristotle University of Thessaloniki,
- Research Committee of the Aristotle University of Thessaloniki,
- Aristotle University of Thessaloniki,
- Prefecture of Thessaloniki,
- Ministry of Education,
- Publishing Ziti

and has been technically co-sponsored by the IEEE Circuits and Systems Society.

We thank all the sponsors for their support.

We do hope that this will give you a good opportunity to discuss new trends and wish you fruitful and inspiring days in Thessaloniki.

June 2009

On behalf of the organizers

Nikos Karampetakis

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# nDS 2009 Program*

| Monday<br>June 29, 2009 | Tuesday<br>June 30, 2009 | Wednesday<br>July 1, 2009 |
|---|---|---|
| 8:30 - 9:10<br>**Registration** | | |
| 9:10 - 9:30<br>**Opening** | | |
| 9:30 - 10:30<br>**MoP**<br>Plenary Talk<br>*Paula Rocha* | 9:00 - 10:00<br>**TuP**<br>Plenary Talk<br>*Anton Kummert* | 9:00 - 10:00<br>**WeP**<br>Plenary Talk<br>*Danwei Wang* |
| 10:30 - 11:00<br>**Coffee Break** | 10:00 - 10:30<br>**Coffee Break** | 10:00 - 10:30<br>**Coffee Break** |
| 11:00 - 13:05<br>**Mo1**<br>Regular Session<br>*Multidimensional Systems 1* | 10:30 - 12:35<br>**Tu1**<br>Regular Session<br>*Multidimensional Signal Processing* | 10:30 - 12:35<br>**We1**<br>Regular Session<br>*Multidimensional Systems 2* |
| 13:05 - 15:00<br>**Lunch**<br>(ArtO2 - Ristorarte Teloglion) | 12:35 - 14:35<br>**Lunch**<br>(ArtO2 - Ristorarte Teloglion) | 12:35 - 14:35<br>**Lunch**<br>(ArtO2 - Ristorarte Teloglion) |
| 15:00 - 16:15<br>**Mo2**<br>Invited Session<br>*Multidimensional Systems Related To Operator Algebras, Operator Theory and Stochastics* | 14:35<br>**Social Program**<br>*Excursion to Vergina* | 14:35 - 15:50<br>**We2**<br>Regular Session<br>*Repetitive Processes 1* |
| 16:15 - 16:45<br>**Coffee Break** | | 15:50 - 16:20<br>**Coffee Break** |
| 16:45 - 18:00<br>**Mo3**<br>Invited Session<br>*Multidimensional Systems Related To Operator Algebras, Operator Theory and Stochastics* | | 16:20 - 17:35<br>**We3**<br>Regular Session<br>*Repetitive Processes 2* |
| 21:00<br>**Workshop Dinner**<br>(Miami Restaurant) | | 17:40<br>**Closing** |

*All Sessions are held in **Teloglion Foundation of Art**.

# **Program** Monday, June 29

| | | |
|---|---|---|
| **MoP** | Plenary Talk | **Stabilization of nD Behaviors**<br>**Chair:** ***E. Zerz*** |
| MoP.1 | 09:30 – 10:30 | Stabilization of *n*D Behaviors<br>*P. Rocha* |
| | 10:30 – 11:00 | **Coffee Break** |
| **Mo1** | Regular Session | **Multidimensional Systems 1**<br>**Chair:** ***T. Kaczorek*** |
| Mo1.1 | 11:00 – 11:25 | Strongly Autonomous Behaviors over Finite Rings<br>*E. Zerz* |
| Mo1.2 | 11:25 – 11:50 | Stability of Positive Fractional 2D Linear Systems with Delays<br>*T. Kaczorek* |
| Mo1.3 | 11:50 – 12:15 | Controlled and Conditioned Invariance with Stability for Two-Dimensional Systems<br>*L. Ntogramatzidis, M. Cantoni* and *R. Yang* |
| Mo1.4 | 12:15 – 12:40 | On Some Nonlinear Second Order Control Systems<br>*D. Bors* and *S. Walczak* |
| Mo1.5 | 12:40 – 13:05 | Approximation of *n*D Systems Using Tensor Decompositions<br>*F. van Belzen* and *S. Weiland* |
| | 13:05 – 15:00 | **Lunch** (ArtO2, Ristorarte Teloglion) |
| **Mo2** | Invited Session | **Multidimensional Systems Related to Operator Algebras, Operator Theory and Stochastics**<br>**Chair:** ***J. Ball*** |
| Mo2.1 | 15:00 – 15:25 | A White Noise Approach to Linear Stochastic Systems<br>*D. Alpay* and *D. Levanony* |
| Mo2.2 | 15:25 – 15:50 | State Feedback for Overdetermined 2D Systems: Pole Placement for Bundle Maps over an Algebraic Curve<br>*L. Shaul* and *V. Vinnikov* |
| Mo2.3 | 15:50 – 16:15 | Rational Functions in Noncommutating Variables, Their Realizations, and Applications to Linear Matrix Inequalities<br>*V. Vinnikov* |
| | 16:15 – 16:45 | **Coffee Break** |
| **Mo3** | Invited Session | **Multidimensional Systems Related to Operator Algebras, Operator Theory and Stochastics**<br>**Chair:** ***V. Vinnikov*** |
| Mo3.1 | 16:45 – 17:10 | Livšic Realization of 2D - Behaviors with Degree One Autonomy<br>*J. Ball* and *G. Boquet* |
| Mo3.2 | 17:10 – 17:35 | A W*-Correspondence Approach to Multi-Dimensional Linear Dissipative Systems<br>*J. Ball* and *S. ter Horst* |
| Mo3.3 | 17:35 – 18:00 | A Natural Transfer Function Space for Linear Discrete Time-Invariant and Scale-Invariant Systems<br>*D. Alpay* and *M. Mboup* |
| | 21:00 | **Workshop Dinner** (Miami Restaurant) |

# Stabilization of nD Behaviors

**Chair:** ***E. Zerz***

MoP.1 09:30 – 10:30

## Stabilization of *n*D Behaviors

*P. Rocha*

In the behavioral framework, system interconnection and control are treated essentially in terms of behavior intersection. After a brief overview of the basic ideas of *n*D system interconnection and the definition of a notion of *n*D stability, we focus on the problem of *n*D system stabilization. We consider both full and partial interconnections, the former corresponding to a situation where all the system variables may be used for control, the latter to a situation where only some of the system variables may be used for control purposes.

# Mo1

Regular Session

11:00 – 13:05

## Multidimensional Systems 1

**Chair:** ***T. Kaczorek***

Mo1.1 11:00 – 11:25

### Strongly Autonomous Behaviors over Finite Rings

*E. Zerz*

We give a new characterization of strong autonomy of linear shift-invariant multidimensional behaviors over finite rings. Unlike earlier descriptions of the concept, the new notion coincides directly with known results on past-determinedness when applied to the special case of one-dimensional systems of this type. This is a first step towards formulating a well-posed initial value problem for systems of partial difference equations over finite rings, a question of interest from the point of view of convolutional coding theory.

Mo1.2 11:25 – 11:50

### Stability of Positive Fractional 2D Linear Systems with Delays

*T. Kaczorek*

A new concept of the practical stability of the positive fractional 2D linear systems is proposed. Necessary and sufficient conditions for the practical stability and the asymptotic stability of the positive fractional 2D systems are established. It is shown that the checking of the practical stability and the asymptotic stability of positive fractional 2D linear systems can be reduced to testing the stability of corresponding 1D positive linear systems. A new concept of the practical stability of the positive fractional 2D linear systems is proposed. Necessary and sufficient conditions for the practical stability and the asymptotic stability of the positive fractional 2D systems are established. It is shown that the checking of the practical stability and the asymptotic stability of positive fractional 2D linear systems can be reduced to testing the stability of corresponding 1D positive linear systems.

# Mo1

Regular Session
11:00 – 13:05

## Multidimensional Systems 1

**Chair:** ***T. Kaczorek***

Mo1.3 11:50 – 12:15

### Controlled and Conditioned Invariance with Stability for Two-Dimensional Systems

*L. Ntogramatzidis, M. Cantoni* and *R. Yang*

This paper collects, in a unified way, some recent results on a geometric approach to two-dimensional (2-D) system analysis and synthesis. The concepts of controlled and conditioned invariant subspaces, stabilisability and detectability subspaces, and output-nulling and input-containing subspaces, which prove useful in solving various 2-D filtering and decoupling problems, are developed for the Fornasini-Marchesini model in a general form.

Mo1.4 12:15 – 12:40

### On Some Nonlinear Second Order Control Systems

*D. Bors* and *S. Walczak*

In this paper, we consider control systems governed by second order differential equations. Sufficient conditions for the existence of solutions and the corresponding stability criteria are proved. Moreover, conditions for the existence of optimal processes are presented. The systems under investigation have natural technical and physical interpretation.

# Multidimensional Systems 1

**Chair:** ***T. Kaczorek***

Mo1.5 12:40 – 13:05

## Approximation of *n*D Systems Using Tensor Decompositions


*F. van Belzen* and *S. Weiland*



This paper considers reduced order modelling of systems with multiple independent variables. The method of Proper Orthogonal Decompositions (POD) is a data-based method that is suitable for the reduction of large-scale distributed systems. In this paper we propose a generalization of the POD method so as to take the *n*D nature of the distributed model into account. Suitable projection spaces can be computed by associating a tensor with the measurement data and computing a suitable decomposition of this tensor. We demonstrate how prior knowledge about the structure of the model reduction problem can be used to improve the quality of approximations. The tensor decomposition techniques are demonstrated on a data approximation example and then the model reduction process is illustrated using a heat diffusion problem.

# Mo2

Invited Session
15:00 – 16:15

## Multidimensional Systems Related to Operator Algebras, Operator Theory and Stochastics

**Chair:** ***J. Ball***

Mo2.1 15:00 – 15:25

### A White Noise Approach to Linear Stochastic Systems

*D. Alpay* and *D. Levanony*

We present a new approach to study linear stochastic systems, where randomness is also included in the transfer function. We use the white noise setting, and the systems input - output relation is given in terms of two convolutions. The Hermite transform allows to describe the results in terms of functions analytic in a countable number of variables.

Mo2.2 15:25 – 15:50

### State Feedback for Overdetermined 2D Systems: Pole Placement for Bundle Maps over an Algebraic Curve

*L. Shaul* and *V. Vinnikov*

We discuss the pole placement problem for overdetermined multidimensional systems. We begin with a brief introduction to the theory of operator vessels, showing that the transfer function of a vessel is a meromorphic bundle map between vector bundles of rank $r$ over an algebraic curve. Next, we define the pole placement problem for vessels. Finally, we present a full solution to the problem in the case $r = 1$. In case the curve is a line, the system is equivalent to a 1D system, but in the general case, the genus and the degree provides an obstruction for placing poles.

# Mo2

Invited Session

15:00 – 16:15

# Multidimensional Systems Related to Operator Algebras, Operator Theory and Stochastics

**Chair:** ***J. Ball***

Mo2.3 15:50 – 16:15

## Rational Functions in Noncommutating Variables, Their Realizations, and Applications to Linear Matrix Inequalities

*V. Vinnikov*

Rational functions in noncommuting variables occur in many areas of system theory: most control problems involve rational expressions in matrix parameters. There are also recognizable formal power series in the theory of formal languages and finite automata, and rational expressions in Hilbert space operators modelling the uncertainty in robust control. The very construction of the underlying mathematical object - the skew field of noncommutative rational functions - is highly nontrivial, hinging on a deep theorem of Amitsur. I will survey some of these basics, as well as the realization theory for noncommutative rational functions due originally to Schutzenberger and Fliess, and revisited recently by J. Ball and his co-workers. I will describe also some features of the noncommutative differential and difference calculus, developed recently in a joint work with D. Kalyuzhniy-Verbovetskii. All these are essential tools for studying one of the most fundamental issues of semidefinite programming in the context of dimension-independent problems: given a set, when is it a feasibility set for an SDP problem, and how can we construct explicitly the corresponding Linear Matrix Inequalities (LMIs).

# Mo3

Invited Session

16:45 – 18:00

# Multidimensional Systems Related to Operator Algebras, Operator Theory and Stochastics

**Chair:** ***V. Vinnikov***

Mo3.1 16:45 – 17:10

## Livšic Realization of 2D - Behaviors with Degree One Autonomy

*J. Ball* and *G. Boquet*

Early work on behaviors associated with *n*D systems emphasized two extreme types of behaviors, namely, autonomous (no free variables) and controllable (existence of a global trajectory patching together the past part of some trajectory with the future part of some other trajectory). It was shown that any behavior can be decomposed as an autonomous part plus a controllable part. Later work gave a more refined classification of autonomous behaviors: nonautonomous behaviors are those with a free variable defined over the whole lattice and have autonomy degree 0 while autonomous behaviors are now further classified into those with autonomy degree $k$ for $k = 1, 2, \ldots, N, \infty$, where $k = \infty$ for the zero behavior and otherwise $N$-$k$ is the maximal dimension of a sublattice on which it is possible to assign a free variable. Independently of this work with motivation from multivariable operator theory, Livšic and co-workers introduced a certain type of overdetermined 2-D input/state/output linear system where inputs and outputs are required to satisfy their own compatibility difference equations. The purpose of this note is to identify the place of Livšic systems in the behavioral framework: the input-output behavior of a Livšic system roughly can be characterized as a 2-D behavior with autonomy degree equal to 1.

# Mo3

Invited Session

16:45 – 18:00

# Multidimensional Systems Related to Operator Algebras, Operator Theory and Stochastics

**Chair:** ***V. Vinnikov***

Mo3.2 17:10 – 17:35

## A W*-Correspondence Approach to Multi-Dimensional Linear Dissipative Systems

*J. Ball* and *S. ter Horst*

Recent work of the operator algebraists P. Muhly and B. Solel, primarily motivated by the theory of operator algebras and mathematical physics, delineates a general abstract framework where system theory ideas appear in disguised form. These system-theory ingredients include: system matrix for an input/state/output linear system, $Z$-transform from a "time domain" to a "frequency domain", and $Z$-transform of the output signal given by an observation function applied to the initial condition plus a transfer function applied to the $Z$-transform of the input signal. Here we set down the definitions and main results for the general Muhly-Solel formalism and illustrate them for two specific types of multi-dimensional linear systems:

(1) dissipative Fornasini-Marchesini state-space representations with transfer function equal to a holomorphic operator-valued function on the unit ball in $\mathbb{C}^d$, and

(2) noncommutative dissipative Fornasini-Marchsini linear systems with evolution along a free semigroup and with transfer function defined on the noncommutative ball of strict row contractions on a Hilbert space.

# Mo3

Invited Session
16:45 – 18:00

# Multidimensional Systems Related to Operator Algebras, Operator Theory and Stochastics

**Chair:** ***V. Vinnikov***

Mo3.3 17:35 – 18:00

## A Natural Transfer Function Space for Linear Discrete Time-Invariant and Scale-Invariant Systems

*D. Alpay* and *M. Mboup*

In a previous work, we have defined the scale shift for a discrete-time signal and introduced a family of linear scale-invariant systems in connection with character-automorphic Hardy spaces. In this paper, we prove a Beurling-Lax theorem for such Hardy spaces of order 2. We also study an interpolation problem in these spaces, as a first step towards a finite dimensional implementation of a scale invariant system. Our approach uses a characterization of character-automorphic Hardy spaces of order 2 in terms of classical de Branges Rovnyak spaces.

# **Program** Tuesday, June 30

| | | |
|---|---|---|
| **TuP** | Plenary Talk | **Fundamentals and Application Results for Multidimensional Circuits**<br>**Chair:** ***K. Galkowski*** |
| TuP.1 | 09:00 – 10:00 | Fundamentals and Application Results for Multidimensional Circuits<br>*A. Kummert* |
| | 10:00 – 10:30 | **Coffee Break** |
| **Tu1** | Regular Session | **Multidimensional Signal Processing**<br>**Chair:** ***A. Kummert*** |
| Tu1.1 | 10:30 – 10:55 | 2D Line Filters for Vision-Based Lane Detection and Tracking<br>*A. Haselhoff* and *A. Kummert* |
| Tu1.2 | 10:55 – 11:20 | A Realization Framework Based on a Natural State Space Description of Discrete *k*-D Signal Processing Systems<br>*J. Velten, S. Schauland* and *A. Kummert* |
| Tu1.3 | 11:20 – 11:45 | 3D Wave Digital Filter Implementation on a Virtex2 FPGA Board with External SDRAM<br>*H. Li, A. Kummert, S. Schauland* and *J. Velten* |
| Tu1.4 | 11:45 – 12:10 | Insufficiencies of the Practical BIBO Stability Concept with Regard to Signal Processing Systems<br>*S. Schauland, J. Velten, A. Kummert* and *K. Galkowski* |
| Tu1.5 | 12:10 – 12:35 | On Generalized Separation and the Speedup of Local Operators on Multi-Dimensional Signals<br>*S. Pfeiffer, M. Mai, W. Globke* and *J. Calliess* |
| | 12:35 – 14:35 | **Lunch** (ArtO2, Ristorarte Teloglion) |
| | 14:35 | **Social Program**<br>*Excursion to Vergina* |

# TuP

Plenary Talk

09:00 – 10:00

# Fundamentals and Application Results for Multidimensional Circuits

**Chair:** ***K. Galkowski***

TuP.1 09:00 – 10:00

## Fundamentals and Application Results for Multidimensional Circuits

*A. Kummert*

Multidimensional circuits represent a highly interesting class of multidimensional (*n*D) continuous systems and are a generalisation of classical Kirchhoff networks. Research in the field of multidimensional circuit theory has been motivated by a variety of applications in the fields image processing, geophysics, modelling of complex multidimensional systems, and numerical integration of partial differential equations. On the one hand, *n*D circuits are known for several decades, on the other its use for industrial applications had been ignored for a long time due to lacking computational power. However, in the meantime fast commercially available hardware allows to reconsider *n*D circuits for challenging signal processing tasks.

# Tu1

Regular Session
10:30 – 12:35

# Multidimensional Signal Processing

**Chair:** ***A. Kummert***

Tu1.1 10:30 – 10:55

## 2D Line Filters for Vision-Based Lane Detection and Tracking

*A. Haselhoff* and *A. Kummert*

In this work a vision-based lane detection system is presented. The main contribution is the application of 2D line filters for lane detection which suppress noise in the near distance without destroying lines in the fare distance. Line pairs are decided to belong to lane markings by means of parallelism is world coordinates and reasonable constraints concerning the road width. The polygon constructed from the detected lane markings is then tracked over time via a kalman filter. Results of the approach are presented in terms of the detection accuracy on a labeled video sequence.

Tu1.2 10:55 – 11:20

## A Realization Framework Based on a Natural State Space Description of Discrete *k*-D Signal Processing Systems

*J. Velten, S. Schauland* and *A. Kummert*

The paper presents a realization framework based on a natural state space description of *n*D systems with a focus on design and analysis of discrete domain linear *k*D systems. While widely used models satisfy control theoretic needs, the presented description addresses design, analysis, and realization of *k*D signal processing systems. It provides a system description that offers better compliance with possible hardware realizations than existing models and thus allows evaluation and consideration of many realization specific effects. Non-causal systems that may be of interest in *k*D signal processing can be described as well as shift operations/delays with respect to more than one coordinate direction.

# Tu1

Regular Session

10:30 – 12:35

# Multidimensional Signal Processing

**Chair:** ***A. Kummert***

Tu1.3 11:20 – 11:45

## 3D Wave Digital Filter Implementation on a Virtex2 FPGA Board with External SDRAM

*H. Li, A. Kummert, S. Schauland* and *J. Velten*

Many *n*D signal processing applications require realization in real time. We propose the realization of a 3D spatio-temporal wave digital filter (WDF) in an FPGA. Optimization of the implemented hardware architecture includes evaluation of two different kinds of overflow handling, namely by saturation and a “modulo 2” type operation. The FPGA board is processing DVI signals that can be provided by usual PC hardware. The processing output is observed in real time on an LCD monitor.

Tu1.4 11:45 – 12:10

## Insufficiencies of the Practical BIBO Stability Concept with Regard to Signal Processing Systems

*S. Schauland, J. Velten, A. Kummert* and *K. Galkowski*

In this paper the practical BIBO stability concept introduced by Agathoklis and Bruton is analyzed with respect to its applicability in the field of signal processing applications. In the field of *n*D signal processing signals are often bounded to all but one dimension like be the time-direction of a spatio-temporal signal, for instance. This property makes the use of systems which meet the conditions of practical BIBO stability, mainly known from the field of control theory, appear to be feasible. However, it can be shown that practical stability in its original form is not sufficient in signal processing if not further conditions are supposed. This is done by comparing the 2D Fourier transform of the actually measured impulse response of exemplary systems to the frequency response expected on basis of the transfer function. Additionally, an application example is given to verify the presented observations.

# Tu1

Regular Session

10:30 – 12:35

## Multidimensional Signal Processing

**Chair:** ***A. Kummert***

Tu1.5 12:10 – 12:35

### On Generalized Separation and the Speedup of Local Operators on Multi-Dimensional Signals

*S. Pfeiffer, M. Mai, W. Globke* and *J. Calliess*

Along with the boom of computer vision - and other signal processing-based applications, the question of fast local operator application has become increasingly important over the past decade. For two-dimensional signals, such as images, local operator separation has proven to ameliorate the computational effort incurred by prominent operators such as mean filter, binomial filter or Sobel filter. However, many modern days' applications involve higher-dimensional input signals including tomography, functional magnetic resonance imaging (fMRI), selective plane illumination microscopy (SPIM), confocal laser scanning microscopy (CLSM), special image fusion. In this work, we generalize previous separation methods in order to make them applicable to input spaces of arbitrary (but finite) dimensionality. We show how this approach renders the computational effort of the dominant multiplicative part of local filter application linear both in size and dimension. Thus, filtering can become feasible for input signals whose dimensionality and size complexity would otherwise be prohibitively high. Finally, we present experiments that demonstrate our approach to be highly beneficial not only in theory but also in practice.

# **Program** Wednesday, July 1

| | | |
|---|---|---|
| **WeP** | Plenary Talk | **Extension of Learnable Bandwidth for Iterative Learning Control**<br>**Chair:** ***A. Kummert*** |
| WeP.1 | 09:00 – 10:00 | Extension of Learnable Bandwidth for Iterative Learning Control<br>*D. Wang* |
| | 10:00 – 10:30 | **Coffee Break** |
| **We1** | Regular Session | **Multidimensional Systems 2**<br>**Chair:** ***E. Zerz*** |
| We1.1 | 10:30 – 10:55 | Dynamic Programming for 2D Discrete Nonlinear Systems<br>*M. Dymkov, K. Galkowski* and *E. Rogers* |
| We1.2 | 10:55 – 11:20 | Empirical Mode Decomposition for Vectorial Bi-Dimensional Signals<br>*N. Azzaoui, A. Miraoui, H. Snoussi* and *J. Duchêne* |
| We1.3 | 11:20 – 11:45 | On Kalman Filtering for 2D System in Fornasini-Marchesini Form<br>*R. Yang, L. Ntogramatzidis* and *M. Cantoni* |
| We1.4 | 11:45 – 12:10 | POLMAT Library now within Symbolic Math Toolbox for Matlab in Multidimensional Systems Computations<br>*P. Augusta* and *Z. Hurák* |
| We1.5 | 12:10 – 12:35 | A Generalization of the Poincaré-Miranda Theorem with an Application to the Controllability of Nonlinear Repetitive Processes<br>*D. Idczak* and *M. Majewski* |
| | 12:35 – 14:35 | **Lunch** (ArtO2, Ristorarte Teloglion) |
| **We2** | Regular Session | **Repetitive Processes 1**<br>**Chair:** ***K. Galkowski*** |
| We2.1 | 14:35 – 15:00 | Linear Quadratic OL-Nash Games on Repetitive Processes with Smoothing on the Gas Dynamics<br>*T. Azevedo - Perdicoúlis* and *G. Jank* |
| We2.2 | 15:00 – 15:25 | A Simplified Approach to Iterative Learning Control Based on Strong Practical Stability of Repetitive Processes<br>*P. Dabkowski, K. Galkowski and E. Rogers* |
| We2.3 | 15:25 – 15:50 | New Robust Stability and Stabilization Conditions for Linear Repetitive Processes<br>*W. Paszke* and *O. Bachelier* |
| | 15:50 – 16:20 | **Coffee Break** |
| **We3** | Regular Session | **Repetitive Processes 2**<br>**Chair:** ***R. Rabenstein*** |
| We3.1 | 16:20 – 16:45 | Iterative Learning Control for Wave Linear Repetitive Processes<br>*B. Cichy, K. Galkowski, E. Rogers* and *A. Kummert* |
| We3.2 | 16:45 – 17:10 | Implicit Discretization of Linear Partial Differential Equations and Repetitive Processes<br>*R. Rabenstein* and *P. Steffen* |
| We3.3 | 17:10 – 17:35 | Subspace Approach to Identification of Linear Repetitive Processes<br>*A. Janczak* and *D. Kujawa* |
| | 17:40 | **Closing** |

# WeP

Plenary Talk

09:00 – 10:00

# Extension of Learnable Bandwidth for Iterative Learning Control

**Chair:** ***A. Kummert***

WeP.1 09:00 – 10:00

## Extension of Learnable Bandwidth for Iterative Learning Control

*D. Wang* and *B. Zhang*

This paper describes frequency domain formulation of iterative learning control systems and study on their convergence along the operation axis. The concepts of learnable bandwidth and monotonic convergence are addressed and analyzed. It is Shown that learnable bandwidth is a critical indicator for monotonic convergence and performance quality of the learning process. To achieve the good learning, various solutions are proposed to tune this learnable bandwidth along operation. There are two approaches, off line and online tuning along operation repetition axis. In this paper, some approaches to extend the learnable bandwidth in various domains are discussed. Experimental results for these approaches show the potentials and effects of learnable bandwidth tuning. Some open problems are provided as well.

# We1

Regular Session
10:30 – 12:35

## Multidimensional Systems 2

**Chair:** ***E. Zerz***

We1.1 10:30 – 10:55

### Dynamic Programming for 2D Discrete Nonlinear Systems

*M. Dymkov, K. Galkowski* and *E. Rogers*

In this paper the dynamic programming approach is generalized to 2D discrete nonlinear systems. In particular, a generalized Bellman function is introduced and then to develop necessary and sufficient optimality conditions for a onlinear optimization problem associated with the systems considered. Finally, with a view to application to examples, an alternative to this function is developed which gives more computationally tractable necessary conditions for optimality.

We1.2 10:55 – 11:20

### Empirical Mode Decomposition for Vectorial Bi-Dimensional Signals

*N. Azzaoui, A. Miraoui, H. Snoussi* and *J. Duchêne*

In this work, an Empirical Mode Decomposition (EMD) of bivariate signals is proposed. It permits to decompose signals into elementary rotating functions, oscillating functions and tendencies. The technique is based on recursive extraction of non planar and rapidly rotating functions, and then a recursive extraction of rapidly oscillating functions as in case of univariate EMD. Our concept is based on a theoretical decomposition and is confirmed on simulated signals.

## Multidimensional Systems 2

**Chair:** ***E. Zerz***

We1.3 11:20 – 11:45

### On Kalman Filtering for 2D System in Fornasini-Marchesini Form

*R. Yang, L. Ntogramatzidis and M. Cantoni*

This paper deals with the problem of signal estimation for two-dimensional Fornasini-Marchesini models. In particular, we approach the problem without pre-imposing a structure on the filter. It is shown that, although it retains a recursive structure, the filter is not immediately expressible in the form of a Fornasini-Marchesini model.

We1.4 11:45 – 12:10

### POLMAT Library now within Symbolic Math Toolbox for Matlab in Multidimensional Systems Computations

*P. Augusta* and *Z. Hurák*

This paper demonstrates convenient use of freely available Polmat library for computations with transfer function models of multidimensional systems within Matlab environment. Polmat functions rely on MuPAD, a computer algebra system, which has become the core engine for symbolic computations in Matlab. Basic manipulations with multivariate two-sided polynomials are illustrated, test of stability of spatially distributed systems and solution of linear (Diophantine) equations with multivariate polynomials are demonstrated by means of a few examples.

# Multidimensional Systems 2

**Chair:** ***E. Zerz***

We1.5 12:10 – 12:35

## A Generalization of the Poincaré-Miranda Theorem with an Application to the Controllability of Nonlinear Repetitive Processes

*D. Idczak* and *M. Majewski*

In the first part of the paper, we prove a generalization of the classical Poincaré-Miranda theorem to the case of a denumerable set of continuous functions of denumerable number of variables. The second part of the paper concerns the controllability of nonlinear repetitive processes. First, we formulate a theorem on the existence of a unique solution to such process and theorem on the continuous dependence of solutions on controls. Next, we use the obtained generalization of Poincaré -Miranda theorem to prove a result on the controllability of nonlinear repetitive process.

# We2

Regular Session
14:35 – 15:50

## Repetitive Processes 1

**Chair:** ***K. Galkowski***

We2.1 14:35 – 15:00

### Linear Quadratic OL-Nash Games on Repetitive Processes with Smoothing on the Gas Dynamics

*T. Azevedo - Perdicoúlis and G. Jank*

This article presents necessary and sufficient results for existence and uniqueness of an equilibrium of a *N*-player Nash game with quadratic performance criteria and an affine repetitive process with smoothing describing the two dimensional (2D) system dynamics, under open loop information pattern. The gas dynamics in a single pipeline is modelled in this theoretical framework, and an algorithm withdrawn from the exposed procedure to calculate the equilibrium point is applied to a simple network example.

We2.2 15:00 – 15:25

### A Simplified Approach to Iterative Learning Control Based on Strong Practical Stability of Repetitive Processes

*P. Dabkowski, K. Galkowski* and *E. Rogers*

This paper develops significant new results on the design of Iterative Learning Control (ILC) schemes based on treating the problem within the framework of the stability/control theory for linear repetitive processes. In particular, so-called strong practical stability is used and it is shown that this can be used to effect in cases where the performance specifications are placed on both error convergence and transient performance.

# We2

Regular Session
14:35 – 15:50

## Repetitive Processes 1

**Chair:** ***K. Galkowski***

We2.3 15:25 – 15:50

### New Robust Stability and Stabilization Conditions for Linear Repetitive Processes

*W. Paszke* and *O. Bachelier*

This paper focuses on the problem of robust stabilization for differential or discrete linear repetitive processes. The provided conditions allow us to involve parameter dependent Lyapunov functions. An additional flexibility in finding a solution is obtained by introducing slack matrix variables. A simulation example is given to illustrate the theoretical developments.

# We3

Regular Session
16:20 – 17:35

# Repetitive Processes 2

**Chair:** ***R. Rabenstein***

We3.1 16:20 – 16:45

## Iterative Learning Control for Wave Linear Repetitive Processes

*B. Cichy, K. Galkowski, E. Rogers* and *A. Kummert*

Iterative Learning Control (ILC) is one application area for the class of 2D linear systems known as repetitive processes where recently experimental evidence to support the performance possible by this approach has been reported. In this paper, we extend the ILC approach to the class of 2D linear systems that often arise from discretization of partial differential equations and, in particular, spatio-temporal dynamics. Application of ILC scheme to a system with such dynamics adds, in effect, one extra indeterminate (the trial number) to the process description and results in the need to analyze a 3D system. The results developed in this paper are the first on ILC control law design and the performance possible is illustrated by numerical simulations.

We3.2 16:45 – 17:10

## Implicit Discretization of Linear Partial Differential Equations and Repetitive Processes

*R. Rabenstein* and *P. Steffen*

Implicit schemes are a popular approach to the discretization of linear partial differential equations by finite differences. They require to solve a linear set of equations in each time step. Since finite difference discretizations lead to a local coupling, these systems of equations are sparse and can be effectively solved by iterative procedures. Numerical procedures of this type are known in control theory as repetitive processes. They have mostly been used to describe control algorithms for processes where passes of finite length are repeated over and over. This contribution shows how the implicit discretization of partial differential equations can be cast into the framework of repetitive processes. Thus it establishes a link between yet unrelated results in numerical mathematics and control theory.

# Repetitive Processes 2

**Chair:** ***R. Rabenstein***

We3.3 17:10 – 17:35

## Subspace Approach to Identification of Linear Repetitive Processes


*A. Janczak* and *D. Kujawa*



The aim of this paper is to propose a new approach to the identification of linear repetitive processes based on subspace algorithms. The order of a linear repetitive process and the unknown process matrices are determined based on the input and output sequences of the actual pass and the output sequence of the previous pass. The identification procedure can be restarted consecutively starting from the first pass data and boundary conditions. The proposed approach can be very useful not only for time invariant linear repetitive processes but also for processes with slowly evolving dynamics or processes which dynamics changes rapidly from pass to pass. Simulation example is provided to illustrate the effectiveness of the proposed approach.

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