**CDPS 2015**

# 9th Workshop on Control of Distributed Parameter Systems

# Program and Abstract

*June 29th - July 3 rd, 2015, Beijing, China*

北京理工大学
BEIJING INSTITUTE OF TECHNOLOGY

# Welcome to CDPS 2015

Welcome to the 9 th Workshop on Control of Distributed Parameter Systems (CDPS), June 29th - July 3 rd, 2015, in Beijing Institute of Technology, Beijing, China! The CDPS workshop is to bring together control scientists who are working in distributed parameter systems control, but different types of expertise, to exchange new ideas, methods, developments, and challenges in this exciting, fast developing control field.

We hope it will be an inspiring and enjoyable meeting.

Jun-Min Wang and Bao-Zhu Guo
Organizers of CDPS 2015

## About the CDPS

**CDPS**, the control of distributed parameter systems, is indisputably at the leading edge of the field of mathematical control theory. Since its inception in the 1960's, along with modern control theory, the field of DPS has undergone a burst of growth since the 1970's, and rapid developments since the 1980's. Although the general aims are the same as for lumped parameter systems, the speciality of DPS lies in its infinite-dimensional nature. This gives rise to distinctive features. These include modelling mainly via partial differential equations (PDEs); the solutions of the open and closed-loop system in the underlying state space, i.e., Banach or Hilbert spaces; control designs; feedback syntheses; computations and visualizations locations of actuators and sensors, as well as structural properties like controllability, observability, and optimal control. Each of these problems may lead to even more sophisticated mathematical problems. Although the control theory for DPS has attained a certain level of maturity, the opportunities and challenges are still numerous for e.g., linear DPS especially for multi-dimensional PDEs with uncertainties, nonlinear PDEs, and stochastic PDEs. Investigations into these will lead to a wealth of new system theoretic results for DPS.

## CDPS Conference History

The eight previous CDPS meeting were held in:

2013 8th Workshop on Control of Distributed Parameter Systems
Craiova, Romania, July 1st - 5th, 2013

2011 7th Workshop on Control of Distributed Parameter Systems,
Wuppertal, Germany, July 18th - 22nd, 2011

2009 IFAC Workshop on Control of Distributed Parameter Systems
Institut Superieur de l'Aeronautique et de l'Espace, Toulouse, France, July 20th - 24th, 2009

2007 IFAC Workshop on Control of Distributed Parameter Systems
University of Namur, Belgium, July 23rd - 27th, 2007

2005 International Workshop on Control of Infinite-Dimensional Systems
University of Waterloo, Canada, July 25th - 29th, 2005

2003 International Workshop on Infinite-Dimensional Dynamical Systems
University of Exeter, UK, July 14th - 18th, 2003

2001 Workshop on Pluralism in Distributed Parameter Systems
University of Twente, Enschede, The Netherlands, July 2nd - 6th, 2001

1998 Modelling and control of infinite-dimensional systems
Leeds, UK, September 2nd - 11th, 1998

## CDPS Steering Committee

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|---|---|
| Michael Demetriou | Worcester Polytechnic Institute, USA |
| Denis Dochain | Université Catholique de Louvain, France |
| Piotr Grabowski | AGH University of Science and Technology, Poland |
| Bao-Zhu Guo | The Chinese Academy of Sciences, China |
| Birgit Jacob | Bergische Universität Wuppertal, Germany |
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| Hartmut Logemann | University of Bath, UK |
| Denis Matignon | Institut Supérieur de l'Aéronautique et de l'Espace, France |
| Kirsten Morris | University of Waterloo, Canada |
| Jonathan Partington | University of Leeds, UK |
| Seppo Pohjolainen | Tampere University of Technology, Finland |
| Olof Staffans | Åbo Akademi University, Finland |
| Marius Tucsnak | Université de Lorraine, Institut Élie Cartan de Lorraine, France |
| George Weiss | Tel Aviv University, Israel |
| Joseph Winkin | University of Namur, Belgium |
| Enrique Zuazua | Basque Center for Applied Mathematics, Spain |
| Hans Zwart | University of Twente, Netherlands |

# Conference Information

## CDPS Organizing Committee

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|---|---|
| Jie Chen | Beijing Institute of Technology |
| Bao-Zhu Guo | The Chinese Academy of Sciences, China |
| Hai Jin | Beijing Institute of Technology |
| Bing Sun | Beijing Institute of Technology |
| Yu-Bing Tian | Beijing Institute of Technology |
| Jun-Min Wang | Beijing Institute of Technology |
| Houbao Xu | Beijing Institute of Technology |
| Qiong Zhang | Beijing Institute of Technology |

## Venue

The venue for the CDPS 2015 is the Lecture Room of Teaching Building for the Post-graduate.

## Registration

The CDPS 2015 registration desk will be open on

| | |
|---|---|
| Sunday June 28, 10:00-20:00 | BIT International Education Exchange Center |
| Monday June 29, 7:30-17:00 | Teaching Building for the Post-graduate |

## Sponsors

The organization of the CDPS 2015 is sponsored by the following institutions and organizations:

Beijing Institute of Technology

Academy of Mathematics and Systems Science, Chinese Academy of Sciences

National Natural Science Foundation of China

973 National Key Basic Research and Development Plan

# Technical Program

## Monday June 29, 2015

| | | |
|---|---|---|
| 08:00-08:30 | Bao-Zhu Guo | Welcome and Opening of CDPS 2015 |

**Morning Session (08:30-12:10, Chair: Hans Zwart)**

| | | |
|---|---|---|
| 08:30-09:10 | Tatsien Li | Exact Synchronization and Approximate Synchronization for a Coupled System of Wave Equations with Dirichlet Boundary Controls |
| 09:10-09:50 | George Weiss | Stabilization of a fluid-rigid body system |
| 09:50-10:10 | Tea Break | |
| 10:10-10:50 | Denis Matignon | Fluid-Structure Interaction: A Port-Hamiltonian Systems Approach |
| 10:50-11:30 | Jiongmin Yong | Solvability of Forward-Backward Evolution Equations |
| 11:30-12:10 | Goong Chen | Modeling the Global Failure of Aircraft Fuselage in Water Entry Using a Plastic Beam Model |

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|---|---|
| 12:10-14:30 | Lunch |

**Afternoon Session (14:30-18:10, Chair: George Weiss)**

| | | |
|---|---|---|
| 14:30-15:10 | Yutaka Yamamoto | Pseudorational transfer functions - a class of infinite-dimensional systems |
| 15:10-15:50 | Xu Zhang | Memory-Type Null Controllability of Evolution Equations |
| 15:50-16:10 | Tea Break | |
| 16:10-16:50 | Bernhard Maschke | Boundary Port Hamiltonian Systems with A Moving Interface : Examples and Properties |
| 16:50-17:30 | Alessandro Macchelli | Energy-Based Control of Distributed Port-Hamiltonian Systems |
| 17:30-18:10 | Qiong Zhang | Stability Analysis of a Wave Equation with K-V Damping |

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|---|---|
| 18:30-20:00 | Supper |

## Tuesday June 30, 2015

**Morning Session (08:30-12:10, Chair: Yutaka Yamamoto)**

| | | |
|---|---|---|
| 08:30-09:10 | Shige Peng | Controlling and Covering Financial Risk under Distribution Uncertainty |
| 09:10-09:50 | Hans Zwart | Exponential Stability of a Linearised PDE Implies Local Exponential Stability? |
| 09:50-10:10 | Tea Break | |
| 10:10-10:50 | Andras Balogh | Feedback Control of Navier-Stokes Equations over Subdomains |
| 10:50-11:30 | Lionel Rosier | Null controllability of one-dimensional parabolic equations by the flatness approach |
| 11:30-12:10 | Qihong Chen | Variational Inequality, Financial Engineering and Optimal Control of Obstacle |

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|---|---|
| 12:10-14:30 | Lunch |

**Afternoon Session (14:30-18:10, Chair: Bingyu Zhang)**

| | | |
|---|---|---|
| 14:30-15:10 | Serge Nicaise | Control and stabilization of 2x2 Hyperbolic Systems on Graphs |
| 15:10-15:50 | Zhuangyi Liu | Optimal Damping for Some Elastic Systems |
| 15:50-16:10 | Tea Break | |
| 16:10-16:50 | Kenji Kashima | Selective Pattern Formation of Reaction-Diffusion Systems |
| 16:50-17:30 | Cheng-Zhong Xu | Control and Regulation of a Fluid Flow System Described by Hyperbolic PDE |
| 17:30-18:10 | Hongwei Lou | Optimization of the Principal Eigenvalue for Elliptic Operators |

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|---|---|
| 18:30-20:00 | Supper |

## Wednesday July 1, 2015

**Taking a rest for one day**

## Thursday July 2, 2015

### Morning Session (08:30-12:10, Chair: Sergei A. Avdonin)

| | | |
|---|---|---|
| 08:30-09:10 | Seppo A. Pohjolainen | Recent Developments on Robust Regulation of Infinite-Dimensional Systems |
| 09:10-09:50 | Shanjian Tang | Dynamic Programming for General Linear Quadratic Optimal Stochastic Control with Random Coefficients |
| 09:50-10:10 | Tea Break | |
| 10:10-10:50 | Kazufumi Ito | Nonsmooth Optimal Control Problems |
| 10:50-11:30 | Bopeng Rao | Exact Boundary Controllability for a Coupled System of Wave Equations with Neumann or Robin Boundary Controls |
| 11:30-12:10 | Hang Gao | Null Controllability for One-dimensional Linear Degenerate Wave Equation |

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|---|---|
| 12:10-14:30 | Lunch Time |

### Afternoon Session (14:30-18:10, Chair: Denis Matignon)

| | | |
|---|---|---|
| 14:30-15:10 | Sergei A. Avdonin | Control and Inverse Problems for Networks of Vibrating Strings with Attached Masses |
| 15:10-15:50 | Gengsheng Wang | Bang-bang Properties of Minimal Time and Norm Controls for Some Evolution Systems |
| 15:50-16:10 | Tea Break | |
| 16:10-16:50 | Orest V. Iftime | From a Canonical Factorization to a J-spectral Factorization for a Class of Infinite-Dimensional Systems |
| 16:50-17:30 | Han-Xiong Li | Space/Time Separation Based Hybrid Learning Control Design for Rapid Thermal Processing System |
| 17:30-18:10 | Genqi Xu | Feedback Stabilization of the Systems with Delays |

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| 19:00-21:00 | Conference Dinner |

## Friday July 3, 2015

**Morning Session (08:30-12:10, Chair: Zhuangyi Liu)**

| | | |
|---|---|---|
| 08:30-09:10 | Arnaud Münch | Inverse problems for linear hyperbolic equations using mixed formulations |
| 09:10-09:50 | Pengfei Yao | Why We Need Riemannian Geometry for Control of the Wave Equation with Variable Coefficients |
| 09:50-10:10 | Tea Break | |
| 10:10-10:50 | Noboru Sakamoto | Stable Manifold Approach for Hamilton-Jacobi Equations in Optimal Control Theory with Applications |
| 10:50-11:30 | Bingyu Zhang | Boundary Integral Operator and Its Applications |
| 11:30-12:10 | Enming Feng | Parameter Identification for a Class of Nonlinear Nonsmooth Distributed Parameter Systems and Applications |

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|---|---|
| 12:10-14:30 | Lunch Time |

**Afternoon Session (14:30-18:10, Chair: Bao-Zhu Guo)**

| | | |
|---|---|---|
| 14:30-15:10 | Ionel Roventa | Approximation of the Controls for the Beam Equation with Vanishing Viscosity |
| 15:10-15:50 | Shuzhi Sam Ge/Wei He | Dynamics and Vibration Control of Flexible Systems |

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|---|---|---|
| 15:50-16:00 | Bao-Zhu Guo | Closing of CDPS 2015 |

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|---|---|
| 17:30-19:00 | Supper |

# Program and Abstract

## Technical Program for Monday June 29, 2015

08:00-08:30
**Welcome and Opening of CDPS 2015**

Chair: **Bao-Zhu Guo**

08:30-12:10
**Morning Session**

Chair: **Hans Zwart**

08:30-09:10 MoA01

*Exact Synchronization and Approximate Synchronization for a Coupled System of Wave Equations with Dirichlet Boundary Controls*

Tatsien Li Fudan University

In this talk we will introduce the exact boundary synchronization and the exact boundary synchronization by groups for a coupled system of wave equations with Dirichlet boundary controls, and establish a complete theory on them.

09:10-09:50 MoA02

*Stabilization of a fluid-rigid body system*

**George Weiss** Tel Aviv University

We consider the mathematical model of a rigid ball moving in a viscous incompressible fluid occupying a bounded domain Ω, with an external force acting on the ball. We investigate in particular the case when the external force is what would be produced by a spring and a damper connecting the center of the ball h to a fixed point $h_1 \in \Omega$. If the initial fluid velocity is sufficiently small, and the initial h is sufficiently close to $h_1$, then we prove the existence and uniqueness of global (in time) solutions for the model. Moreover, in this case, we show that h converges to $h_1$, and all the velocities (of the fluid and of the ball) converge to zero. Based on this result, we derive a control law that will bring the ball asymptotically to the desired position $h_1$ even if the initial value of h is far from $h_1$, and the path leading to $h_1$ is winding and complicated. Now, the idea is to use the force as described above, with one end of the spring and damper at h, while other end is jumping between a finite number of points in Ω, that depend on h (a switching feedback law).

09:50-10:10

Tea Break

| 10:10-10:50 | MoA03 |
|---|---|

*Fluid-Structure Interaction: A Port-Hamiltonian Systems Approach*

**Denis Matignon** Institut Supérieur de l'Aéronautique et de l'Espace

The first part of this talk will be devoted to a review of classical models of fluid mechanics in 2D or 3D, such as Euler and Navier-Stokes equations. We aim at showing that port-Hamiltonian systems can encompass many physically meaningful models: compressible/incompressible, potential/rotational, linear/nonlinear, inviscid / viscous. The thermodynamical hypotheses will be recalled. The specific variables classically used in fluid mechanics, such as velocity potential, stream function or vorticity, will appear in a very natural and physically meaningful way in this formalism. We will also address simpler 1D models, such as Webster horn equation, and shallow water (also known as Saint-Venant) equation; in both cases, care will be taken to identify the appropriate boundary variables as port variables.

In the second part of the talk, we will apply the interconnection facility provided by port-Hamiltonian systems to sloshing, a typical Fluid-Structure Interaction problem. In airplanes, the coupled vibrations between fluid and structural dynamics can lead to structural fatigue, noise and even instability. At ISAE, we have an experimental device that consists of a cantilevered plate with a fluid tank near the free tip. This device is being used for model validation and active control studies. Port-Hamiltonian systems formulation is being used for the structured modeling of this experimental device: structural dynamics and fluid dynamics are modeled independently as infinite-dimensional systems; the plate is approximated as a Euler-Bernoulli beam, and shallow water equations are used for representing the fluid in the moving tank. The global system is finally easily coupled thanks to the interaction ports of the pHs elementary models. Finally for a numerical simulation objective, the spatial discretization of the infinite-dimensional systems using mixed finite-element method is performed, and gives rise to a finite-dimensional system that is still Hamiltonian; comparisons between experimental results and numerical simulations will be presented, and can already be found on the WEB site [2].

References

[1] Cardoso-Ribeiro, F.L., Pommier-Budinger, V., Schotte, J.S., and Arzelier, D. (2014). Modeling of a coupled fluid-structure system excited by piezoelectric actuators. In IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 216–221.

[2] Cardoso-Ribeiro, F.L., Matignon, D. and Pommier-Budinger, V. (2015). Modeling of a fluid-structure coupled system using port-Hamiltonian formulation. In IFAC Workshop on Lagrangian and Hamiltonian Methods in Non Linear Control (LHMNLC'15), (invited session), 6 p. http://github.com/flavioluiz/port-hamiltonian

| 10:50-11:30 | MoA04 |
|---|---|

*Solvability of Forward-Backward Evolution Equations*

**Jiongmin Yong** University of Central Florida /Fudan University

For a standard optimal control problem of evolution equations, by applying Pontryagin's maximum principle, one obtains a necessary condition for the optimal control, involving a coupled system of two evolution equations, one is an initial value problem (a forward equation) and the other is a terminal value problem (a backward equation). We therefore call the system a forward-backward evolution equation (FBEE, for short). Once such an FBEE is solvable, we obtain a candidate of optimal state-control pair. Usually, one has to assume that the time duration to be small enough to guarantee the solvability of such an FBEE. In this talk, we will report some results from an on-going research of FBEEs.

| 11:30-12:10 | MoA05 |
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*Modeling the Global Failure of Aircraft Fuselage in Water Entry Using a Plastic Beam Model*

**Goong Chen** Texas A&M University

In the study of aircraft crashing into water such as the disasters of the Malaysia Airlines Flight MH370 and Air Asia's Flight 8501, the impact may not be large enough to cause local failure of fracture, unlike the case of crashing on land. However, the impact can induce large bending moment on the fuselage, causing severe global failure of the breakup and disintegration of the fuselage into multiple segments. In this talk, the speaker will model the aircraft fuselage as a plastic free-free beam. Beam theories and equations involved will be discussed. The model will then be applied to the data obtained from CFD (computational fluid dynamics) simulations of aircraft water entry to study the structural failure of the aircraft in this dynamic process.

12:10-14:30
**Lunch Time**

14:30-18:10
**Afternoon Session**

Chair: **George Weiss**

| 14:30-15:10 | MoB01 |
|---|---|

*Pseudorational transfer functions - a class of infinite-dimensional systems*

**Yutaka Yamamoto** Kyoto University

We give an overview of the class of pseudorational transfer functions. This class consists of the ratio of entire functions of exponential type that are Laplace transforms of distributions with compact support. This class gives a convenient platform for dealing with distributed systems whose state space is determined by bounded-time data. Delay-differential systems, with retarded, neutral or distributed delays, are typical examples. We explore its interesting interplay with the ring of entire functions, and highlight some appealing structures as follows: Starting from a completely general input/output framework, we derive a concrete realization procedure based on the above fractional representation of transfer functions (or impulse responses). It is then also possible to give a complete characterization of spectral properties of such realizations via zeros of the denominator of transfer functions. Such spectral properties allow us to give a stability criterion and also an appropriate relationship between internal and external stability notions. Based on a concrete representation of the state space, we are led to a concrete characterization of left-shift invariant subspaces of H^2. This result has a direct consequence on H-infinity control theory. We give a concise yet comprehensive and unified overview of such results. The paper is concluded with this and also a criterion on the existence of a Bezout identity in this class.

| 15:10-15:50 | MoB02 |
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Memory-Type Null Controllability of Evolution Equations

**Xu Zhang** Sichuan University

This work is addressed to a study of the memory-type null controllability of evolution equations, i.e., by imposing some additional memory-type constraints on the usual null controllability. The problem is reduced to the obtention of suitable observability estimates for the dual systems. For the case of finite dimensions, several Kalman-type rank conditions are derived. The memory-type null controllability of some parabolic equations and hyperbolic equations are also established.

| 15:50-16:10 | |
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Tea Break

| 16:10-16:50 | MoB03 |
|---|---|

*Boundary Port Hamiltonian Systems with A Moving Interface: Examples and Properties*

**Bernhard Maschke** Universite Claude-Bernard (Lyon I)

In this paper we shall consider a class of Distributed Parameter Systems defined as Boundary Port Hamiltonian Systems [2, 3] which spatial domain, assumed to be 1-dimensional, is splitted into subdomains separated by a moving interface. Such systems have been defined for systems of two conservation laws where it had been shown that one may define a extension of a Stokes-Dirac structure including the interface variables [1]. In this paper, we shall extend the definition to a higher number of conservation laws associated to conservative and dissipative systems and illustrate the definition with several examples; In a second instance, we shall analyze the passivity and system's properties of this class of system and analyze different classes of interface relations.

References:

[1] M. Diagne and B. Maschke, Port hamiltonian formulation of a system of two conservation laws with a moving interface. European Journal of Control, 19(6):495 – 504, 2013.

[2] Y. Le Gorrec, H. Zwart and B.M. Maschke, Dirac structures and boundary control systems associated with skew-symmetric differential operators. SIAM J. of Control and Optimization, 44(5):1864–1892, 2005.

[3] H. Zwart, Y. Le Gorrec, B.M. Maschke and J. Villegas, Well-posedness and regularity of hyperbolic boundary control systems on a one-dimensional spatial domain. ESAIM-Control Optimization and Calculus of Variations, 16(4):1077–1093, 2010.

16:50-17:30 MoB04

*Energy-Based Control of Distributed Port-Hamiltonian Systems*

**Alessandro Macchelli** Universita di Bolog

The scope of this talk is to present a general methodology for the synthesis of asymptotic stabilizing boundary control laws for a large class of linear, distributed port-Hamiltonian systems defined on a one-dimensional spatial domain. The starting point is the control by interconnection paradigm (energy-Casimir method) in which the controller is a passive dynamical system that is interconnected to the boundary of the distributed parameter one. Despite the intrinsic limitations of the approach related to the class of systems to which the method is applicable, it is shown that the control action is able to shape the closed-loop Hamiltonian to obtain desired stability properties. These considerations lead to the development of a more general approach based on state feedback able to perform the energy-shaping task even for system with strong dissipation. The idea is to obtain a closed-loop system still in port-Hamiltonian form, but characterized by a new Hamiltonian with a unique and isolated minimum at the desired equilibrium. Asymptotic stability is then obtained via damping injection on the boundary. The general theory is illustrated with the help of some examples.

17:30-18:10 MoB05

*Stability Analysis of a Wave Equation with K-V Damping*

**Qiong Zhang** Beijing Institute of Technology

In this talk, we study a wave system with local Kelvin-Voigt damping. First, for the 1-d system, we prove the precise relationship between the polynomial decay rate and the power of the coefficient function near zero, which says that the energy decays faster when the coefficient function is more continuous near the interface. The method is based on the frequency analysis and several inequalities of Poincare's and Hardy's type. Further, we also analyze the stability of the higher dimensional wave equation with local K-V damping.

## Technical Program for Tuesday June 30, 2015

08:30-12:10
**Morning Session**

Chair: **Yutaka Yamamoto**

08:30-09:10 TuA01

*Controlling and Covering Financial Risk under Distribution Uncertainty*

**Shige Peng** Shandong University

We discuss how to use nonlinear expectation to covering the trading risk in a financial market against loss exposures under distribution uncertainty.

| 09:10-09:50 | TuA02 |
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*Exponential Stability of a Linearised PDE Implies Local Exponential Stability?*

**Hans Zwart** University of Twente

For ordinary differential equations (ode's) it is well-known that that if the linearised equation is exponentially stable, then the non-linear ode is locally exponentially stable. For partial differential equations (pde's) a similar result is known for decades. However, it only holds under additional assumptions on the equation. By means of simple examples we show that these conditions are necessary, i.e., counter example can be constructed when these conditions don't hold.

| 09:50-10:10 | |
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Tea Break

| 10:10-10:50 | TuA03 |
|---|---|

*Feedback Control of Navier-Stokes Equations over Subdomains*

**Andras Balogh** University of Texas - Pan Americ

In this talk we consider an incompressible Navier-Stokes system on a three dimensional bounded domain with non-slip boundary conditions and with feedback control defined over a subdomain. The control is introduced in the form of an additional nonlinear viscosity term. It is non-vanishing only on a subdomain of the main domain and is proportional to the energy dissipation functional on this subdomain. For the controlled system we prove the existence, uniqueness and stability of the strong solution for initial data and forcing term which are arbitrary on the subdomain of control and are sufficiently small outside this subdomain. The existence proof is based on considering the Navier-Stokes system separately on two subdomains with unspecified boundary conditions on the common boundaries, and then using fixed point argument to show the existence of a common boundary interface condition.

| 10:50-11:30 | TuA04 |
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*Null controllability of one-dimensional parabolic equations by the flatness approach*

**Lionel Rosier** Ecole des Mines de Paris

We consider linear one-dimensional parabolic equations with space dependent coefficients that are only measurable and that may be degenerate or singular. Considering generalized Robin-Neumann boundary conditions at both extremities, we prove the null controllability with one boundary control by following the flatness approach, which provides explicitly the control and the associated trajectory as series.

| 11:30-12:10 | TuA05 |
|---|---|

*Variational Inequality, Financial Engineering and Optimal Control of Obstacle*

**Qihong Chen** Shanghai University of Finance and Economics

In recent years, variational inequalities and free boundary problems have been extensively used in many parts of Engineering, Mechanics, Chemistry, and Bioscience etc, even Economics and Finance. This talk is concerned with various optimal control problems (especially, the obstacle control problem) for systems governed by a variational inequality.

12:10-14:30

**Lunch Time**

14:30-18:10

**Afternoon Session**

Chair: **Bingyu Zhang**

| 14:30-15:10 | TuB01 |
|---|---|

*Control and stabilization of 2x2 Hyperbolic Systems on Graphs*

**Serge Nicaise** Université de Valenciennes et du Hainaut Cambrésis

We consider 2x2 (first order) hyperbolic systems on networks subject to general transmission conditions and to some dissipative boundary conditions on some external vertices. We find sufficient but natural conditions on these transmission conditions that guarantee the exponential decay of the full system on graphs with dissipative conditions at all except one external vertices. This result is obtained with the help of a perturbation argument and an observability estimate for an associated wave type equation. An exact controllability result is also deduced.

| 15:10-15:50 | TuB02 |
|---|---|

*Optimal Damping for Some Elastic Systems*

**Zhuangyi Liu** University of Minnesota - Duluth

In this talk, we consider optimal damping for some elastic systems with various kind of damping. Results for two objective functions are compared.

15:50-16:10

Tea Break

| 16:10-16:50 | TuB03 |
|---|---|

*Selective Pattern Formation of Reaction-Diffusion Systems*

**Kenji Kashima** Kyoto University

Autonomous pattern formation phenomena are ubiquitous throughout nature. The goal of this paper is to show the possibility to effectively generate various desired spatial patterns by guiding such phenomena suitably. To this end, we employ a reaction–diffusion system as a mathematical model, and formulate and solve a novel pattern formation control problem. The Turing instabilities play a crucial role throughout the paper. http://authors.elsevier.com/a/1QqlZ1AMujK3M

| 16:50-17:30 | TuB04 |
|---|---|

*Control and Regulation of a Fluid Flow System Described by Hyperbolic PDE*

**Cheng-Zhong Xu** Université Lyon 1

We shall talk about the proportional and integral control of a fluid flow system. The system is described by nonlinear hyperbolic partial differential equations with multi-inputs and multi-outputs. We study first equilibrium states and their local stability for the open-loop system. Then we linearize the nonlinear system around an equilibrium state and design proportional and integral stabilizing controllers for the closed-loop system. Numerical simulations and analysis of asymptotic behaviors are carried out to show performances of the designed controllers.

| 17:30-18:10 | TuB05 |
|---|---|

*Optimization of the Principal Eigenvalue for Elliptic Operators*

**Hongwei Lou** Fudan University

Optimization problems of the principle eigenvalue for elliptic operators are considered. We establish that though the optimal principal eigenvalue for these operators is not always attainable, it can be attained by some elliptic operator formed by lamination of the original operators. We give also necessary conditions on the optimal principal eigenvalue and eigenfunctions.

## Technical Program for Thursday July 2, 2015

08:30-12:10
**Morning Session**

Chair: **Sergei A. Avdonin**

| 08:30-09:10 | ThA01 |
|---|---|

Recent Developments on Robust Regulation of Infinite-Dimensional Systems

**Seppo A. Pohjolainen** Tampere University of Technology

In this paper the robust regulation problem for a distributed parameter system

\dot{x} = Ax + Bu + F_s v; y = Cx + Du + F_m v;

with an infinite-dimensional exosystem

\dot{v} = Sv;

is discussed. The infinite-dimensional feedback controller is of the form

$$\dot{z} = G_1 z + G_2 e; u = Kz:$$

All the spaces involved are infinite-dimensional. The purpose of the feedback controller is to stabilize the closed loop system and to asymptotically track the reference and perturbation signal generated by the exosystem, despite perturbations in the system's parameters.

The famous Internal Model Principle states that a robust feedback controller must contain a copy of the dynamics of the exosystem. Therefore it is difficult or impossible to stabilize the closed loop system exponentially. Instead polynomial, strong, or weak stability must be considered.

The infinite-dimensional Internal Model Principle can be formulated in various ways, in the time and frequency domains. In this presentation the different definitions are presented and their relations will be clarified. The frequency domain formulation is based on a new ring of stable transfer functions.

The theory of finite-dimensional robust controllers was developed independently by Wonham and Francis and at the same time by Davison. Wonham's approach was based on geometric theory while Davison introduced a combination of servo-compensator and stabilizing compensator. This decomposition also holds for infinite-dimensional systems and two approaches are shown to be similar by the formalism used in the presentation.

The presentation reviews and combines the recent results of T. Hamalainen, L. Paunonen. P. Laakkonen and S. Pohjolainen.

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09:10-09:50 ThA02

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*Dynamic Programming for General Linear Quadratic Optimal Stochastic Control with Random Coefficients*

**Shanjian Tang** Fudan University

We are concerned with the linear-quadratic optimal stochastic control problem where all the coefficients of the control system and the running weighting matrices in the cost functional are allowed to be predictable (but essentially bounded) processes and the terminal state-weighting matrix in the cost functional is allowed to be random. Under suitable conditions, we prove that the value field $V(t, x, \Omega)$, $(t, x, \Omega)\in [0,T]\times R^n \times \Omega$, is quadratic in x, and has the following form: $V(t, x)=< K_tx, x>$ where K is an essentially bounded nonnegative symmetric matrix-valued adapted processes. Using the dynamic programming principle (DPP), we prove that K is a continuous semi-martingale of the form

$$K_t = K_0 - \int_0^t dk_s + \int_0^t \sum_{i=1}^d L_s^i dW_s^i, \qquad t \in [0,T]$$

with k being a continuous process of bounded variation and the stochastic integral

$$\int_0^t \sum_{i=1}^d L_s^i dW_s^i$$

being a BMO martingale; and that (K, L) with $L:= (L^1, \cdots, L^d)$ is a solution to the associated backward stochastic Riccati equation (BSRE), whose generator is highly nonlinear in the unknown pair of processes. The uniqueness is also proved via a localized completion of squares in a self-contained manner for a general BSRE. The existence and uniqueness of adapted solution to a general BSRE was initially proposed by the French mathematician J. M. Bismut [in SIAM J. Control & Optim., 14(1976), pp.419-444, and in Seminaire de Probabilites XII, Lecture Notes in Math. 649, C. Dellacherie, P. A. Meyer, and M. Weil, eds., Springer-Verlag, Berlin, 1978, pp.180-264], and subsequently listed by Peng [in Control of Distributed Parameter and Stochastic Systems (Hangzhou, 1998), S. Chen, et al., eds., Kluwer Academic Publishers, Boston, 1999, pp.265-273] as an open problem for backward stochastic differential equations. It had remained to be open until a general solution by the author [in SIAM J. Control & Optim., 42(2003), pp.53-75] via the stochastic maximum principle with a viewpoint of stochastic flow for the associated stochastic Hamiltonian system. The present talk introduces the second but more comprehensive (seemingly much simpler, but appealing to the advanced tool of Doob-Meyer's decomposition theorem, in addition to the DDP) adapted solution to a general BSRE via the DDP. The detailed full paper is referred to SIAM J. Control Optimization. 53(2), 2015.

09:50-10:10

Tea Break

10:10-10:50 ThA03

*Nonsmooth Optimal Control Problems*

**Kazufumi Ito** North Carolina State University

A class of nonsmooth and nonconvex optimal control problems is discussed. The Lagrange multiplier theory is developed for the optimality condition. Based on the theory numerical algorithms are developed and analyzed. Applications of algorithm and theory are demonstrated.

10:50-11:30 ThA04

*Exact Boundary Controllability for a Coupled System of Wave Equations with Neumann or Robin Boundary Controls*

**Bopeng Rao** Université de Strasbourg

In this talk, we first show the exact boundary controllability for a coupled system of wave equations with Neumann boundary controls. In order to establish the corresponding observability inequality, we introduce a compact perturbation method which does not depend on the Riesz basis property, but depends only on the continuity of projection with respect to a weaker norm. We next observe that the Neumann boundary value problem can be served to obtain the exact boundary controllability with coupled Robin boundary controls. Finally, in the case of less boundary controls, we show the non exact boundary controllability with both Neumann and coupled Robin boundary controls, respectively.

11:30-12:10 ThA05

*Null Controllability for One-dimensional Linear Degenerate Wave Equation*

**Hang Gao** Northeast Normal University

This paper is devoted to studying the null controllability problems for the one-dimensional linear degenerate wave equations. First, we give the well-posedness results for the linear degenerate wave equations. Then, we prove the null controllability for this system when a control acts on the nondegenerate boundary, and we give a result of non-null controllability.

12:10-14:30
**Lunch Time**

14:30-18:10
**Afternoon Session**

Chair: **Denis Matignon**

14:30-15:10 ThB01

Control and Inverse Problems for Networks of Vibrating Strings with Attached Masses

**Sergei A. Avdonin** University of Alaska

We consider control and inverse problems for networks of elastic strings with point masses attached at the interior vertices. For tree-like networks, we prove the exact boundary controllability in a sharp time interval with respect to a Sobolev space which regularity increases with the distance from the boundary at each interior vertex. We demonstrate that the densities of the strings, values of the masses and lengths of the edges can be recovered using the dynamical Dirichlet-to-Neumann map associated with the boundary vertices.

The talk is based on joint work with Nina Avdonina (University of Alaska Fairbanks) and Julian Edward (Florida International University)

15:10-15:50 ThB02

*Bang-bang Properties of Minimal Time and Norm Controls for Some Evolution Systems*

**Gengsheng Wang** Wuhan University

We present another way to approach the bang-bang properties of minimal time and norm control problems for some linear evolution systems. These systems are governed by C_o semigroups with admissible control operators. First we study relationships between reachable subspaces and observable subspaces, these studies lead to two presentation theorems on the dual spaces of the observable spaces; then we derive the maximum principles for minimal norm controls; after that we use the equivalence of minimal norm controls and minimal time controls to get the maximum principle for minimal time controls, through the maximum principle of minimal norm controls; finally, we build up the bang-bang properties via the maximum principle. To get the maximum principle, we impose the assumption that the systems are null controllable from time intervals (This assumption can be indeed relaxed to a weaker one.) To derive the bang-bang properties, we impose the assumptions that the systems are both null controllable from time intervals and have the unique continuation from measurable sets in time.

| 15:50-16:10 | |
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Tea Break

| 16:10-16:50 | ThB03 |
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From a Canonical Factorization to a J-spectral Factorization for a Class of Infinite-Dimensional Systems

**Orest V. Iftime** University of Groningen

Matrix-valued functions in the Wiener class on the imaginary line are considered in this note. This class of functions is large enough to be suitable for many applications in systems and control of infinite-dimensional systems. For this class of functions three kinds of factorization are discussed: (right-)standard factorization (also called noncanonical factorization), canonical factorization, and J-spectral factorization. In particular, we focus on an algorithmic procedure to find a (right-)standard factorization and a J-spectral factorization for matrix-valued functions in the Wiener class under the assumption that such factorizations exists. In practice, the J-spectral factors for irrational functions are usually calculated using rational approximations. We show that approximation using rational functions may be achieved in the Wiener norm.

| 16:50-17:30 | ThB04 |
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*Space/Time Separation Based Hybrid Learning Control Design for Rapid Thermal Processing System*

**Han-Xiong Li** City University of Hong Kong

Temperature distribution estimation and control are critical issues in rapid thermal processing (RTP) system. Except the tracking accuracy, the spatial uniformity and temperature repetitiveness are required during the heating operation. A hybrid learning control is developed based on the space/time separation for handling this difficult problem. The dominant modes of the system are first extracted to construct the reduced model with the help of Galerkin's method, upon which three state estimation methods are then proposed. With the estimated state, the sliding mode control scheme is designed to have the accurate and uniform temperature performance for each operation run. Then, the learning control strategy is designed to work with the sliding mode controller for maintaining the consistency between operation runs.

| 17:30-18:10 | ThB05 |
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*Feedback Stabilization of the Systems with Delays*

**Genqi Xu** Tianjin University

In this talk, we introduce our research development on the feedback stabilization problem of linear dynamic systems with interior delay, input delay and output delay.

Firstly we study the hyperbolic system with interior delay and prove that if the dynamic system without delay is exactly controllable, then the state feedback control law is robust for the interior delay. Secondly we investigate the system with distributed delays. Based on the partial state predictor we structure a dynamic feedback control law to stabilize exponentially the system. Finally we study the stabilization problem of the system with output-delay. By employing the Luenberger observer, we design the feedback control law to stabilize exponentially the system.

# Technical Program for Friday July 3, 2015

08:30-12:10
**Morning Session**

Chair: **Zhuangyi Liu**

08:30-09:10 FrA01

*Inverse problems for linear hyperbolic equations using mixed formulations*

**Arnaud Münch** Universite Blaise Pascal, Clermont-Ferrand

We explore a direct method allowing to solve numerically inverse type problems for hyperbolic type equations. We first consider the reconstruction of the full solution of the wave equation posed in Ω\times (0; T) - Ωa bounded subset of R^N - from a partial distributed observation. We employ a least-squares technic and minimize the L^2-norm of the distance from the observation to any solution. Taking the hyperbolic equation as the main constraint of the problem, the optimality conditions are reduced to a mixed formulation involving both the state to reconstruct and a Lagrange multiplier. Under usual geometric optic conditions, we show the well-posedness of this mixed formulation (in particular the inf-sup condition) and then introduce a numerical approximation based on space-time finite elements discretization. We show the strong convergence of the approximation and then discussed several examples for N = 1 and N = 2. The reconstruction of both the state and the source term is also discussed, as well as the boundary case as well as the parabolic case. Joint works with Nicolae Cindea. Details can be found in [1, 2] using arguments developed in [3, 4].

References

[1] N. Cindea, and A. Munch, Inverse problems for linear hyperbolic equations using mixed formulations. To appear in Inverse Problems. http://arxiv.org/abs/1502.00114

[2] N. Cindea, and A. Munch, Reconstruction of the solution and the source of hyperbolic equations from boundary measurements: mixed formulations. Submitted. (2015).

[3] C. Castro, N. Cindea, and A. Munch, Controllability of the linear one-dimensional wave equation with inner moving forces, SIAM J. Control Optim., 52 (2014), pp. 4027-4056.

[4] N. Cindea and A. Munch, A mixed formulation for the direct approximation of the control of minimal L2-norm for linear type wave equations, Calcolo, 52 (2), 2015, pp. 1-4.

| 09:10-09:50 | FrA02 |
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Why We Need Riemannian Geometry for Control of the Wave Equation with Variable Coefficients

**Pengfei Yao** Academy of Mathematics and Systems Science

We will briefly compare several methods in control of the wave equation with variable coefficients to show that the Riemannian geometrical approach is a useful tool to give checkable assumptions through the curvature theory.

| 09:50-10:10 |
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Tea Break

| 10:10-10:50 | FrA03 |
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*Stable Manifold Approach for Hamilton-Jacobi Equations in Optimal Control Theory with Applications*

**Noboru Sakamoto** Nagoya University

Hamilton-Jacobi equations (HJEs) have been the bottle neck in the application of optimal control theory for many decades. Recent years a progress has been made for solving HJEs via stable manifold theory in dynamical system theory. In this talk, the computational theory of stable manifolds and its algorithm will be introduced for finding the solution of HJEs in optimal control theory. Next in this talk, the applications of the computational method will be presented. The field of applications ranges from aircraft control to mechanical systems with strong emphasis on its applicability to real world problems.

| 10:50-11:30 | FrA04 |
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*Boundary Integral Operator and Its Applications*

**Bingyu Zhang** University of Cincinnati

In this talk, we will discuss how boundary integral operators play important roles in studying non-homogeneous boundary value problems of dispersive wave equations and will demonstrate how those harmonic analysis based tools, which are originally developed in investigating the pure initial problems of nonlinear dispersive wave equations, can be effectively used to study non-homogeneous boundary value problems through the associated boundary integral operators. Especially, we will explain how boundary integral operators can help us to find various hidden regularities of solutions of the Kortweg-de Vries equation and Schrodinger equation.

| 11:30-12:10 | FrA05 |
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*Parameter Identification for a Class of Nonlinear Nonsmooth Distributed Parameter Systems and Applications*

**Enming Feng** Dalian University of Technology

Distributed parameter systems (DPSS) are infinite dimensional dynamical systems. Control theories of DPSS are widely applied in many practical problems. We applied the theories to sea ice, fresh ice, transformer, deep-basin gas, paleo-geo and frozen soil temperature fields.

The main contributions are as follows: 1) Sea ice is an important indicator and an effective modulator of regional and global climate change; 2) Fresh ice is a primary factor in the global climate system; 3) Transformer; 4) Deep-basin gas; 5) Paleo-geo and frozen soil temperature fields.

12:10-14:30
**Lunch Time**

14:30-18:10
**Afternoon Session**

Chair: **Bao-Zhu Guo**

14:30-15:10 FrB01

*Approximation of the Controls for the Beam Equation with Vanishing Viscosity*

**Ionel Roventa** University of Craiova

We study the uniform controllability property and the convergence of a finite difference semi-discrete scheme for the approximation of the boundary controls of a 1-d equation modeling the transversal vibrations of a hinged beam. It is known that, due to the high frequency numerical spurious oscillations, the uniform (with respect to the mesh-size) controllability property of the semi-discrete model fails in the natural setting. Consequently, the convergence of the approximate controls corresponding to initial data in the finite energy space cannot be guaranteed. We prove that, by adding a vanishing numerical viscosity, the uniform controllability property and the convergence of the scheme is ensured. Some numerical experiments which confirm the results are discussed.

15:10-15:50 FrB02

*Dynamics and Vibration Control of Flexible Systems*

**Shuzhi Sam Ge/Wei He** National University of Singapore

The advantages of flexible structures such as lightweight, low energy consumption and high flexibility greatly motivate the applications of flexible structures in the fields of aviation, aerospace, robotics, offshore engineering, etc. However, usage of flexible structures will produce excessive vibrations, which make a negative effect on the system's performance, and even lead to the limited life-span of the flexible structures. Therefore, design of an effective control method for vibration suppression of flexible structures is significant in practice. In the last decades, there have been increasing interests in the modeling and control of flexible mechanical systems. Dynamic modeling and control design of the flexible systems is a challenging task in the field of control systems. For purpose of dynamic analysis, the flexible systems (the flexible string, Euler-Bernoulli beam, and Timoshenko beam) are regarded as distributed parameter systems with infinite dimensions. Dynamic model of the flexible systems is derived by use of the Hamilton's principle. Lyapunov method is used for stability analysis for the closed loop system. Simulation results are given to verify the control performance.

15:50-16:00

**Closing Session**

Chair: **Bao-Zhu Guo**