GDRE CONEDP Meeting 2013

Modeling and control of systems: applications to nano-sciences, environment and energy

Grenoble, April 9-10-11, 2013

Program

1 Invited presentations

1.1 April 9, Environment

1.1.1 Alain Rapaport

Some control and optimization problems for the biological waste-water treatment

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The biological treatement of water ressources in bioreactors often uses mathematical models and automatic control for deriving decision making tools. The simplest model of continously stirred tank reactor (CSTR) is the chemostat one, for which the input flow is the control variable.

For microbial strains with growth inhibition, the system can be unstable in open-loop, requiring a feedback control. But reducing the input flow above its nominal value during the transient requires to have a upstream storage capacity. We shall present different strategies [3, 2] to globally stabilize the process with a constant input flow, playing with spatial inhomogeneity.

The treatment of natural reservoirs of large volumes such as lakes usually require to operate in constant volume, disturbing as little as possible the supported life. For this purpose, we consider the minimal time control control in "closed circuit" with an external bioreactor, and study the influence of spatial inhomogeneity in the continuation of the preliminary work [1].

The models rely on the good knowledge of growth kinetics, especially for determining the optimal steady state in terms of maximization of the production. We shall present a new approach of extremum seeking based on a functional identification of the growth curve [4].

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1.1.2 Pierre-Olivier Malaterre

Modeling, Control and Data Assimilation issues for open-channel hydraulic systems - What to do when we can't get no satisfaction from minimization?

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Several types of natural or artificial open-channel hydraulic systems are managed (here taken in the sense of "operated") in order to satisfy some operational constraints, in presence of external (often unknown) disturbances, and using some real-time measurements on the systems. This general description already introduces the underlying concepts of modeling, control and data assimilation. The objectives of this presentation are (i) to present the problems to be solved on a mathematical point of view but also with some real-case illustrations, (ii) to present some solutions of these problems, (iii) to show the logic of the links between these modeling, control and data assimilation issues which are usually studied in different academic communities, (iv) to make a focus on some problems we face when using classical minimization approaches, provide (partial) solutions and leave some still opened problems for discussion. The illustrations will be given on different classes of open-channel hydraulic systems, such as sewage systems, irrigation canals and rivers.

Sewage systems are usually operated in order to extract the "water" from the system to the treatment plants, in order to prevent overtopping, which can be a big challenge at daily peak flows and specially during storms. One key issue on this type of system is to reduce the accidental releases into the natural environment, and therefore to maximize the use of the available storage volume and treatment capabilities of the sewage plants.

Irrigation canals are operated to convey water from upstream source(s) (dam, river) to users (agricultural lands, but also industries and cities, recreational activities, environmental water bodies, etc). Such systems can be very large: several hundreds of kilometers of canals, several hundreds of m^3/s of nominal flow (ex.: South to North transfert canals in China, Narmada canal in India, Philippe Lamour (BRL) canal and Société du Canal de Provence canals in France). Varying objectives are assigned to their managers. The main general one is to provide water to the different users at the right moment and in the right quantity, to minimize water losses, and to guarantee the safety of the infrastructure. In particular, a major concern is to prevent the canals from overtopping, but also from having water levels inside the pools below the supply depths of the gravity offtakes.

Some rivers, such as the Rhône river, have similarities with these canals in the sense that hydraulic devices (hydropower plants, dams, locks) are located along the course of the river and operated in order to produce hydroelectricity, insure water levels compatible with navigation constraints and limit the negative impact of floods.

An efficient way of operating these structures, specially using automatic controllers, allows to improve the overall performance of the system, and to reduce civil engineering costs (additional reservoirs, size of the system, maintenance of damaged banks, etc). All these systems have in common the fact that they convey water, in open channels, therefore governed by the same underlying equations (Saint-Venant equations). The 1D version of these equations is generally sufficient for such systems. These equations are nonlinear hyperbolic partial differential equations [1].

Some simple control algorithms can be automatically tuned directly on the real systems (e.g.: PID with ATV method), without requiring (explicitly) a model of the process to control. But, most of the more advanced approaches, specially MIMO (Multi-Inputs, Multi-Outputs) ones, need a model of the system, to design and tune the controller. This model, like in any project using a model, needs a calibration phase. For a 1D hydrodynamic model based on Saint-Venant's equations, this often means adjusting roughness coefficients, discharge coefficients at cross and lateral devices, and seepage. Several methods are described in the literature, based on minimization approaches. Whatever algorithm selected, there is nevertheless an important question to address first, which is seldom studied in the literature: "is it possible to identify the parameters I want from the measurements I have?" This first question is linked to what is called "sensitivity". This depends on the relationship between parameters and outputs of the model, but also on the desired precision on the parameters and on the available one on the measurements. Some people introduced the concept of "equifinality" stating that, in some cases, several different sets of parameters give the same model outputs within given uncertainties. This concept is somehow peculiar in the sense that it is used to criticize the model (structure and/or parametrization) itself, whereas it may also be attached to the set of data used for the calibration. An important question is therefore "what type of input scenario would be best (or at least required) to be able to calibrate the model?" This second question can be addressed under some assumptions using the "worst-case" concept. We will present methodologies for answering these 2 questions, and apply them on an example taken from the literature. This shows that having a minimization algorithm is maybe useful, but being able to answer the 2 above questions is even more important [6].

After having obtained a ("good") model, a controller can be designed and tuned (structure and parameters choices). "Good" model is very relative, and not well defined. If the uncertainties on the model can be assessed, the "robust control" approaches can explicitly take them into account during the controller design and tuning phases (ex.: $\mathcal{H}_\infty$, μ analysis, ℓ_1 frameworks). There exist a large spectrum of control methods that have been tested on open-channel hydraulic systems [9]. The one we will present here is based on the ℓ_1 norm minimization. This is justified by taking into account some classical objectives and contraints imposed in the specifications of the controller. One main objective is to minimize the deviations of an output variable around its targeted value. This can be written as minimizing the (ℓ_∞ norm) of some controlled signals z. The cross-structures used as actuators have, also, minimum and maximum allowed gate openings. These constraints are typically time-domain constraints on the bound (ℓ_∞ norm) of some controlled signals z (the z can include some u as we will choose to do). On the other side, a bound on the perturbation w is also known (e.g.: subscribed maximum discharge at offtakes, inflows at tributaries, discharge surges due to the start or stop of a turbine, released volume from a lock), which is also an information on its ℓ_∞ norm. This justifies the idea to design a controller by minimizing the ℓ_1 norm of the impulse response of the considered transfer matrix $\Phi : w \to z$, since this norm is the induced ℓ_∞-ℓ_∞ norm [2, 5, 10]. In addition to the minimization of this norm for some transferts, bounds can be also specified on some of them.

By default, without additional specific care, the obtained ℓ_1 controller does not include integral effects, meaning that steady-state errors can occur. This does exist despite the fact that the controller has been designed minimizing some norm on the outputs to be controlled. We could have naively thought that this minimum would lead to zero steady state-error, but unfortunately it is not the case. This is usually a problem, since the control objectives very often include maintaining a given water level at some strategic point as close as possible to its target. A manager cannot be satisfied by just knowing that is has been somewhat minimized. He wants to have the guaranty that the error (by example between a water level and the corresponding target) will converge towards zero, at least when the disturbances have reached a new steady-state. We will present the principles of the ℓ_1 controller design and show its performances on some bench-mark canal [8]. We will then focus on the introduction of such integral effects into this ℓ_1 controller design. Four different options will be described and compared, the more interesting one being based on the introduction of a time-domain template [7].

After this design and tuning phases, when the controller is available, the computation of control actions at actuators is based on measurements at some characteristic points (feedback control). These measurements can be water levels as well as flows along the hydraulic system and/or at the hydraulic devices. Thus, when failures of sensors occur or during strong transients (such as stopping or starting the hydropower turbines, large change of the water distribution, etc), the regulation process can be disturbed. A solution suggested to detect sensor defaults, to correct the observations and to update the water profiles involved in the calculation of control actions, is based on a data assimilation method (e.g.: Kalman Filter). This method is optimal because it ensures minimizing the estimation error (the trace of the covariance matrix of the a-posteriori state error to be more precise). But (again!) this property is not sufficient for some industrial applications, and in particular in our case. This is why the notions of detectability and convergence of the Kalman Filter have been studied into more details. This study has identified sufficient conditions that ensure the error of the estimate to converge towards a nil average. This issue will be illustrated on a portion of the Rhône river between 2 hydropower plants. In order to test and validate such a method, it has been implemented into the industrial test tool of the Compagnie Nationale du Rhône called "simulation platform" [3, 4]. Examples of usually difficult scenarios simulating a loss of sensor and an unexpected stopping of a turbine will be presented. The reconstruction of unmeasured inflows at tributaries will also show the importance of the number and location of the sensors, allowing (or not) this reconstruction. It allows demonstrating the benefits of the presented solution, and the fact that the minimization used in the Kalman Filter is not always sufficient.

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1.1.3 Marc Bocquet

The iterative ensemble Kalman smoother:
the best of both worlds?

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Data assimilation seeks a mathematically optimal compromise between outcomes of a numerical model that simulates a physical system and observations of that system. It has been successfully used for twenty years in operational meteorology to perform the best forecast, and is now being used or tested in many geoscience fields. Two main classes of methods have taken the lead.

Firstly, *4D-Var* is a method from optimal control theory that finds the most likely initial condition of the system at the beginning of a temporal window. 4D-Var is a variational scheme and minimises on the initial condition a cost function that represents the misfit of the model with the observations and a previous forecast. As a nonlinear smoother it is a powerful method. But it requires the adjoint of the model, which is a formidable technical task for large geophysical models. It is also difficult to extract the uncertainty attached to the optimal initial condition and to pass it to the subsequent analysis.

As an alternative method, the *ensemble Kalman filter* (EnKF) easily propagates the uncertainty with the use of an ensemble of model trajectories. As a filter it does not require the use of the model adjoint. However, the use of a necessarily limited number of ensemble members leads to sampling errors that call for the use of *ad hoc* techniques, namely inflation and localisation, to make the method practical.

We have recently introduced the *iterative ensemble Kalman smoother* (IEnKS) that has the potential of getting the best of both methods. It is not an *hybrid* method as it does not seek to combine both methods. Like 4D-Var, as a nonlinear smoother, it solves for an underlying variational problem, but without the use of the tangent/adjoint model. Like the EnKF, it is a flow-dependent method and propagates the uncertainty. We will show on meteorological toy-models that the method systematically outperforms 4D-Var, the EnKF and even a standard ensemble Kalman smoother. However, as an ensemble method, it is still plagued by sampling errors and the implementation of inflation and localisation still needs investigating in this context.

1.2 April 10, Nano-sciences

1.2.1 Paola Pietra

Electron transport in strongly confined nanostructures: modeling and simulation

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We present an effective mass model, derived in [1], describing the ballistic transport of electrons in ultra-scaled confined nanostructures. Due to the strong confinement, the crystal lattice is considered periodic only in the one dimensional transport direction and an atomistic description of the entire cross–section is given. Using an envelope function decomposition, an effective mass approximation is obtained. The model consists of a sequence of one dimensional device dependent Schrödinger equations, one for each energy band, in which quantities retaining the effects of the confinement and of the transversal crystal structure are inserted. In order to model a gate-all-around Field Effect Transistor, self-consistent computations include the resolution, in the whole 3D domain, of a Poisson equation describing a slowly varying macroscopic potential. Simulations of the electron transport in semiconducting one-walled Carbon Nanotubes are presented, using a classical-quantum hybrid strategy [3]. The ballistic effective mass model is used only in the active region, and it is coupled to a drift-diffusion model (derived for strongly confined nanostructures in [2]) in the source and drain regions.

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1.2.2 Gabriel Stoltz

The microscopic origin of the macroscopic dielectric permittivity of crystals

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The aim of this talk is to present a study of the response of crystals to external, static or time-dependent forcings [3, 4]. The mathematical treatment relies on the properties of localized defects [2] and their time evolutions. In particular, it provides a mathematical analysis of the Adler-Wiser formula [1, 6] relating the (possibly frequency dependent) macroscopic relative permittivity tensor to the microscopic structure of the crystal at the atomic level. It also gives sound foundations to the random phase approximation, a fundamental ingredient of the GW approximation [5] to compute accurate band gaps in photovoltaic materials.

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1.2.3 Gabriel Turinici

Bi-linear control and perturbations

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The controllability of quantum systems is well understood for isolated systems where the control can be implemented exactly. However when perturbations or multiple systems are present some interesting theoretical and numerical questions are raised. We will give in this talk some theoretical and numerical results available for this framework and discuss open questions.

1.3 April 11, Energy

1.3.1 Remy Nouailletas

THE CONTROL OF MAGNETICALLY CONFINED PLASMAS (IN TOKAMAK FACILITIES)

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Fossil fuels (oil, gas, coal) account for approximately 85% of the worldwide sources of primary energy today. But they should run out with in some tens of years and they are responsible for a climate change via the contribution in the greenhouse effect of the CO2 generated by their combustion. Magnetic fusion is one of the options being studied in order to eventually provide an answer to these issues. Several conditions have to be met to produce fusion reactions: the fuels have to be heated up to very high temperature (around 100 million degrees) in order to overcome the electrostatic potential barrier between positively charged nucleuses. To reach such a temperature, the ionized gas or plasma must be confined, for example by magnetic confinement in a so-called tokamak facility, which seems to be the most promising way. The key world project in the domain, ITER (www.iter.org) , is led by seven partners (Europe, United States of America, Japan, China, India, South Korea, Russia) accounting for one half of the world population. The main objective of the ITER project is to demonstrate the scientific feasibility of magnetic fusion. The ITER tokamak facility is currently under construction in Cadarache in France, with first experiment scheduled for 2020.

Tokamak control issues are becoming more and more important for the success of magnetic fusion research and will be crucial for ITER. Feedback control of the main plasma macroscopic parameters, such as plasma position and shape, total current or density is now quite well mastered in the different worldwide tokamaks. But the control of internal plasma radial profiles is still in its infancy, whereas it now appears to be crucial in order both to ensure safe tokamak operation and to sustain high performance plasma regimes. More precisely, it has well known that the so-called safety factor profile is a key parameter for the global stability of plasma discharges and it has also been observed that some specific profiles may generate some enhanced confinement of the plasma energy, which may reduce the size and cost of future fusion reactors. To control his infinite dimension profile, model-based controllers seem to be necessary in front of the complexity of studied physical phenomena and the need of simulation validation before carry out any real experiment.

In this talk, after a short introduction to the fusion energy source development issue, we will focus on the tokamak configuration. The actuators and the diagnostics needed to perform plasma inside this facility will be presented. Then a large overview of the main control requirements for tokamak operations will be proposed. Finally we will detail the plasma infinite dimension profiles control issue. First principles model based on partial differential equations will be presented to illustrate the difficulties of the problem.

1.3.2 Emmanuel Witrant

Profiles Control and Stability in Thermonuclear Fusion: Some Issues for ITER

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Controlled thermonuclear fusion is a topic of prime interest as a source of sustainable energy, which could possibly compete with classical fission reactors in terms of efficiency and as a key process to produce energy. In the forthcoming years, the main challenge for the fusion community will be to develop experimental scenarios for ITER (≪ International Thermonuclear Experimental Reactor ≫, the largest fusion process ever built and with a first run planned for 2018). Amongst the key issues, the main control challenges are related to the plasma shape control, advanced equilibrium profiles for Tokamaks and the stabilization of magnetohydrodynamic (MHD) modes. Shape control has been studied extensively but many results still have to be discovered on the other two topics, where the nonhomogeneous transport of waves, energy and particles appear as fundamental.

After a general overview on fusion and the key issues from the control point of view, the proposed talk will detail some recent advances on current profiles control carried in Tore Supra (CEA Cadarache, South of France). Indeed, a particular interest is given to the current density and the way to produce plasma current. Due to the intrinsic limitation on magnetic flux availability in fusion processes to maintain a purely inductive current, the use of non-inductive sources to generate most of the current is inevitable. Modelling and real-time control of radiofrequency antennas (current source distributed in the plasma) are of prime importance to optimize the confinement and to ensure the profiles robustness with respect to external perturbations.

Another advanced problem for control will also be considered: the stabilization of MHD modes. MHD phenomena have several impacts on plasma; one of them is to generate unstable modes, such as those studied in the Reversed Field Pinch EXTRAP-T2 (Alfv?n lab, KTH, Sweden). These modes are of capital importance in fusion reactors, as a lack of their stabilization leads to the loss of confinement. Their time constant is typically a few milliseconds, with a control cycle of 100 ?s for the simplest feedback rules. The complexity of the dynamics and the real-time constraints motivate new approaches for modelling and control, with an emphasis on time-delays, as discussed in this talk.

1.3.3 François Alouges

Optimal strokes for microswimmers

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Swimming strategies at the microscopic scale involves different mechanisms than in the human scale. Indeed, the flow is dominated by the viscosity effects of the water and becomes reversible. This feature, known as the "scallop theorem" in that context needs to be circumvented when one wants to swim with strokes that produce a net motion of the swimmer.

The talk proposes to make a tour of recent works on this topic by the author and collaborators [1, 2, 3, 4, 5, 6]. In particular, we show how the problem becomes a control problem linear in the control and without drift, while optimizing the strokes with respect to the mechanical energy spent by the swimmer gives rises to an optimal control problem with a natural quadratic cost.

Numerical methods used to find optimal strokes will be also presented as well as numerical results on a few different systems.

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2 Short talks

2.1 April 9

2.1.1 Yann Lepoittevin

Continuous Tracking of Structures from an Image Sequence

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The poster describes an innovative method to simultaneously estimate motion and track a structure on an image sequence. To process noisy images, assumptions on dynamics should be involved. Consequently, the method relies on the dynamics equations of the studied physical system.

The issue of tracking a structure has been largely studied in the image processing literature, see Yilmaz et al. [1]. In Papadakis et al. [2], a method that computes motion field and tracks a structure, based on an incremental 4D-Var approach, is described. But it requires an accurate segmentation of the structure on the whole image sequence. On the other hand, our method only necessitates an approximate segmentation of the object on the first image. To our knowledge, no paper describes such a method that, only based on image data and a rough segmentation, simultaneously estimates motion and segments/tracks a structure.

A strong 4D-Var algorithm, such as described by Le Dimet et al. [3], is used to solve the evolution equation of image brightness, those of motion's dynamics and those of the distance map modelling the tracked structure. The observation data used by the assimilation process are the satellite images and their gradient values. The solution is obtained by minimization of a cost function using the L-BFGS algorithm, described by Zhu et al. in [4].

Promissing results have been obtained on twin experiments in order to quantify the accuracy of the method. The approach has also been tested on satellite acquisitions in order to track clouds an meteorological satellite acquisitions. Further research will concern the conception of a multi-object tracking method.

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2.1.2 Matthias Rabatel

MULTI-SCALE MODELING OF SEA ICE MECHANICS AND DRIFT

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Arctic sea-ice environment is heterogeneous. Indeed, there are areas of high ice concentration, where sea-ice is collected in a large plate, called ice-pack, covering a large surface around the North Pole and there are areas of low ice concentration, called Marginal Ice Zone (MIZ), where sea ‚Äã‚Äãice is separated into a plurality of fragment (floes). These floes may interact with each other through inelastic collisions.
The pack-ice behavior may be compared to a continuous elactic plate encountering progressive damage and the behavior floes in MIZ may be compared to granular medium. At present, models exists to simulate deformations and cracks in the ice-pack [1] and other to simulate collisions between floes [2]. However no models takes into account the whole spectrum of sea-ice behavior. One of the goals of our research is to build a model linking the different behavior.

First, we interested in behavior floes into MIZ and how deal with collisions between floes. Most models, developed for this kind of problem, considers floes as plate rigid bodies with a shape is circular or the same size. Moreover, this models deal with collisions as response to a inter-penetration. It determine contact forces according to a geometry of the inter-penetration. In order to be more realistic, we build a model where floes can have irregular shape and different size and we determine contact forces according to a kinematic and a geometry of the floes [3]. Thus, we deal with collisions before they lead to a inter-penetration.

This model is implemented using Matlab. In differents configuration, we could check symmetry conservation *Bernoulli's problem*, we could observed kinetic energy dissipation and we could noted a good propagation of impact *Newton's Cradle*.

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2.1.3 Lukas Jakabcin

The Modeling Of Geological Materials for The Numerical Simulation Of Collisions Of Continental Plates

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The collision of the Indian sub-continent with Asia involves complex mechanisms of deformation: the creation and propagation of faults which accommodate the extrusion of continental blocks, the thickening of the crust of the Earth. Our goal is to develop a simplified numerical model that should account for the main phenomena that interact in such collisions [1]. In this model, the crust is considered to be a visco-elasto-plastic material in which cracks are allowed to propagate. This hypothesis is qualitatively supported by analogue experiments showing faults propagation in a layer of plasticine (Asian crust) deformed by a rigid indenter (Indian crust), which extrudes blocks away from the indenter path. The evolution of the medium is based on the minimisation of an energy that depends on the displacement, the elastic and plastic deformation and on a phase-field function that tracks the location and propagation of cracks. We prove the existence of solutions and the Clausius-Duhem inequality [2]. We describe the numerical method used to simulate indentation experiments in 2D and present numerical results.

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2.2 April 10

2.2.1 Jérôme Lohéac

Optimal control of a nonholonomic integrator
Application to micro-swimmers

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This talk is devoted to the study of the time optimal controllability of an $(n+1)$-dimensional nonholonomic differential system with constraint on the state variables. The problem I consider arises from the motility problem in a Stokes fluid or more precisely, the swimming problem for microorganisms. This problem has been motivated by the work [6], where controllability of axi-symmetrical micro-swimmers is studied. In this talk, I will give explicit time optimal control for a problem arising from this work. The result given in this talk can be found in [5].

Nonholonomic systems have been intensively studied in numerous works and I only refer to Bloch [3] where a comprehensive survey is given in connection with control theory. Minimum time control problems for nonholonomic systems have also been considered in the literature and explicit optimal solutions have been computed when no constraint is imposed on the state variables. The case $n = 2$, i.e. when only two controls are considered, is studied in Bloch [3]. The n-dimensional control case we consider is a generalization of the Brockett integrator. The generalization that I consider is different from the one originally given in Brockett [4] but corresponds to the $(2n + 1)$-dimensional Heisenberg systems studied in Beals, Gaveau and Greiner [2] and Agrachev, Barilari and Boscain [1] in the framework of sub-Riemannian geometry. The minimal time problem for the nonholonomic system, can be interpreted as a sub-Riemannian geodesic problem. A study of the geodesics of the sub-Riemannian manifold induced by the Heisenberg group can be found in Beals, Gaveau and Greiner [2], see also Prieur and Trélat [7] or Agrachev, Barilari and Boscain [1]. All these studies are performed without any state constraint. As far as I know, there is no explicit optimal solutions when constraints are imposed on the state variables.

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2.2.2 Felipe Castillo

BOUNDARY OBSERVERS FOR LINEAR AND QUASI-LINEAR HYPERBOLIC SYSTEMS

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In this work we consider the problem of boundary observer design for one-dimensional first order linear and quasi-linear strict hyperbolic systems with n rightward convecting transport PDEs. By means of Lyapunov based techniques, we derive some sufficient conditions for exponential boundary observer design using only the information from the boundary control and the boundary conditions. We consider static as well as dynamic boundary controls for the boundary observer design. The main results are illustrated on the model of an inviscid incompressible flow.

2.2.3 Ying Tang

Lyapunov stability of a singularly perturbed system of two conservation laws

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The singular perturbation techniques occurred at the beginning of the 20th century (see [1]). The development of this method led to the efficient use in various fields in mathematical physics and engineering, for instance, fluid mechanics, fluid dynamics, elasticity, quantum mechanics, chemical-reactor, aerodynamics etc. (see [2] for a survey). Lyapunov methods are usually used for stability analysis of dynamical systems. This is also true for those dynamics with a small perturbation parameter. In the work of [3], a quadratic-type Lyapunov function has been investigated for a singularly perturbed finite-dimensional nonlinear system.

In our work, systems modelled by singularly perturbed partial differential equations (PDEs) are considered. More precisely a class of systems of two conservation laws with a small perturbation parameter ϵ is investigated. By setting $\epsilon = 0$ the singularly perturbed system is divided as two subsystems: the reduced and boundary-layer systems. Each of the two systems has a Lyapunov function and is asymptotically stable under suitable boundary conditions. For a sufficiently small perturbation parameter, the stability of the singularly perturbed system of conservation laws can be obtained by a Lyapunov function which is given by a convex combination of the Lyapunov function of the reduced and boundary-layer systems.

The work is organized as 4 parts. The first part introduces the singularly perturbed system of conservation laws. The second part presents the stability of the reduced and boundary-layer systems. The third part shows the stability for the overall singularly perturbed system. In the last part an illustrative example is provided to show the main result.

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2.3 April 11

2.3.1 Jacques Blum

Optimization of trajectories in Tokamak discharges by optimal control methods.

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The optimization of scenarii to achieve thermonuclear conditions has a great importance in the reseach for controlled fusion by magnetic confinement and especially for the ITER Tokamak. The idea is to optimize the external poloidal magnetic field system in order to achieve a desired trajectory (plasma current ramp-up, plateau, desired plasma boundary,..).

An evolutive model has been written, which is based on the coupling between 2D axisymmetric equations for the magnetic poloidal flux (Maxwell equations + Grad-Shafranov equilibrium equation) and a 1D resistive diffusion equation inside the plasma. Consistency between the two systems is ensured by an iterative process based on the boundary conditions of the two systems.

Sequential quadratic programming methods have been used in order to minimize a cost-function which is the sum of the quadratic difference between the desired trajectory and the simulated one and the energetic cost of the system. An adjoint state has been derived for this complicate coupled system, which enables to compute the gradient of the cost-function. Then the voltages applied to the external circuits can be computed in time in order to minimize this cost-function. The open-loop control of a certain trajectory can thus be computed by this algorithm.

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2.3.2 Aditya Gahlawat

Using sum-of-square polynomials for the analysis and control of parabolic partial differential equations

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This talk covers the area of Sum-of-Squares Polynomials (SOSPs) for the analysis and control of parabolic partial differential equations (PDEs). SOS framework allows us to set up linear matrix inequality (LMI) constraints for the analysis and synthesis problem. Thus, the method discussed is an algorithmic approach for the analysis and control of PDEs. The problem of solving LMI problems is computationally tractable. Moreover, excellent algorithms exist to tackle these problems in polynomial time. In particular, the talk will consider a one-dimensional linear parabolic PDEs with spataílly distributed coeÔ¨Écients. The coefficients are distributed polynomially. This class of PDEs is considered since various physical quantities which undergo the processes of diffusion, advection and reaction can by modelled in a satisfactory manner using these PDEs. This talk will go over the following topics:

- Introduction to SOSPs.
- Positive operators on Hilbert spaces parameterized by polynomials.
- Construction of Lyapunov functionals using polynomially parameterized operators.
- Full-state feedback based boundary controller synthesis.
- Observer based boundary controller synthesis using point observation.

2.3.3 Pierre-Olivier Lamare

LYAPUNOV TECHNIQUES FOR STABILIZATION OF SWITCHED LINEAR SYSTEMS OF CONSERVATION LAWS

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In this paper, the exponential stability in L^2-norm is investigated for a class of switched linear systems of conservation laws. The state equations and the boundary conditions are both subject to switching. We consider the problem of synthesizing stabilizing switching controllers. By means of Lyapunov techniques, three control strategies are developed based on steepest descent selection, possibly combined with a hysteresis and a low-pass filter. Some numerical examples are considered to illustrate our approach and to show the merits of the proposed strategies.

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