



IN PARTNERSHIP WITH:
CNRS

Ecole Polytechnique

**Ecole nationale supérieure des
techniques avancées**

Activity Report 2015

Project-Team COMMANDS

Control, Optimization, Models, Methods and
Applications for Nonlinear Dynamical Systems

IN COLLABORATION WITH: Centre de Mathématiques Appliquées (CMAP), Unité de Mathématiques Appliquées (UMA - ENSTA)

RESEARCH CENTER
Saclay - Île-de-France

THEME
**Optimization and control of dynamic
systems**

Table of contents

1. Members	1
2. Overall Objectives	2
2.1. Scientific directions	2
2.2. Industrial impact	2
3. Research Program	2
3.1. Historical aspects	2
3.2. Trajectory optimization	3
3.3. Hamilton-Jacobi-Bellman approach	3
4. Application Domains	4
4.1. Fuel saving by optimizing airplanes trajectories	4
4.2. Hybrid vehicles	4
4.3. Energy production planning	4
5. Highlights of the Year	4
6. New Software and Platforms	4
6.1. BOCOP	4
6.2. Bocop Avion	5
6.3. Bocop HJB	5
7. New Results	5
7.1. Optimal control of ordinary differential equations	5
7.1.1. Periodic optimal controls for the Purcell microswimmer	5
7.1.2. Study of optimal health insurance policies	5
7.2. Optimal control of partial differential equations	6
7.2.1. Local minimization algorithms for dynamic programming equations	6
7.2.2. Suboptimal feedback control of PDEs by solving HJB equations on adaptive sparse grids	6
7.2.3. Numerical approximation of level set power mean curvature flow	6
7.3. Finance and stochastic control	6
7.3.1. Second order Pontryagin's principle for stochastic control problems	6
7.3.2. On the convergence of the Sakawa-Shindo algorithm in stochastic control	6
7.3.3. Optimal multiple stopping problems	7
7.4. Electricity production	7
7.4.1. Equilibria over energy markets	7
7.4.2. Energy management for a micro-grid	7
7.5. Energy management in transport	8
7.5.1. Energy management for an hybrid vehicle	8
7.5.2. Collaboration with the startup Safety Line	8
8. Bilateral Contracts and Grants with Industry	8
8.1.1. IFPEN	8
8.1.2. Safety Line	9
9. Partnerships and Cooperations	9
9.1. Regional Initiatives	9
9.2. International Initiatives	9
9.3. International Research Visitors	9
9.3.1. Visits of International Scientists	9
9.3.2. Visits to International Teams	9
10. Dissemination	9
10.1. Promoting Scientific Activities	9
10.1.1. Scientific events organisation	9
10.1.1.1. General chair, scientific chair	9
10.1.1.2. Member of the organizing committees	9

10.1.2. Scientific events selection	10
10.1.2.1. Member of the conference program committees	10
10.1.2.2. Organization of sessions	10
10.1.3. Journal	10
10.1.3.1. Editorial boards	10
10.1.3.2. Reviewer - Reviewing activities	10
10.1.4. Leadership within the scientific community	10
10.1.5. Research administration	10
10.2. Teaching - Supervision - Juries	10
10.2.1. Teaching	10
10.2.2. Supervision	10
10.2.3. Juries	11
10.3. Popularization	11
11. Bibliography	11

Project-Team COMMANDS

Creation of the Project-Team: 2009 January 01

Keywords:

Computer Science and Digital Science:

- 6.2.1. - Numerical analysis of PDE and ODE
- 6.2.6. - Optimization
- 6.2.7. - High performance computing
- 6.3.2. - Data assimilation
- 6.4.1. - Deterministic control
- 6.4.2. - Stochastic control

Other Research Topics and Application Domains:

- 4.3.1. - Smart grids
- 7.1.2. - Road traffic
- 7.1.3. - Air traffic
- 7.2.1. - Smart vehicles

1. Members

Research Scientists

Joseph Frederic Bonnans [Team leader, Inria, Senior Researcher, HdR]
Axel Kroner [Inria, Starting Research position, from Oct 2014]
Pierre Martinon [Inria, Researcher]

Engineer

Olivier Tissot [Inria, from Dec 2014]

PhD Students

Florine Bleuse [Paris Saclay, until Sep 2015]
Nicolas Grebille [EDF, until Aug 2015, granted by CIFRE]
Christopher Hermosilla [Inria, until Mar 2015]
Benjamin Heymann [Ecole Polytechnique]
Athena Picarelli [Inria, until Jan 2015]
Cédric Rommel [Paris Saclay, from Nov 2015, granted by CIFRE]
Faisal Wahid [Ecole Polytechnique, until Jun 2015]
Justina Gianatti [U. Rosario (Argentina), until Nov 2015]

Administrative Assistant

Jessica Gameiro [Inria]

Others

Angeline Bertrand [Internship, May-Aug 2015]
Marco Encina [Internship, Jan-Mar 2015]
Ivan Cadena Guaqueta [stagiaire ECP, until Feb 2015]

2. Overall Objectives

2.1. Scientific directions

Commands is a team devoted to dynamic optimization, both for deterministic and stochastic systems. This includes the following approaches: trajectory optimization, deterministic and stochastic optimal control, stochastic programming, dynamic programming and Hamilton-Jacobi-Bellman equation.

Our aim is to derive new and powerful algorithms for solving numerically these problems, with applications in several industrial fields. While the numerical aspects are the core of our approach it happens that the study of convergence of these algorithms and the verification of their well-posedness and accuracy raises interesting and difficult theoretical questions, such as, for trajectory optimization: qualification conditions and second-order optimality condition, well-posedness of the shooting algorithm, estimates for discretization errors; for the Hamilton-Jacobi-Bellman approach: accuracy estimates, strong uniqueness principles when state constraints are present, for stochastic programming problems: sensitivity analysis.

2.2. Industrial impact

For many years the team members have been deeply involved in various industrial applications, often in the framework of PhD theses or of postdocs. The Commands team itself has dealt since its foundation in 2009 with several types of applications:

- Space vehicle trajectories, in collaboration with CNES, the French space agency.
- Aeronautics, in collaboration with the startup Safety Line.
- Production, management, storage and trading of energy resources, in collaboration with EDF, GDF and TOTAL.
- Energy management for hybrid vehicles, in collaboration with Renault and IFPEN.

We give more details in the Bilateral contracts section.

3. Research Program

3.1. Historical aspects

The roots of deterministic optimal control are the “classical” theory of the calculus of variations, illustrated by the work of Newton, Bernoulli, Euler, and Lagrange (whose famous multipliers were introduced in [65]), with improvements due to the “Chicago school”, Bliss [41] during the first part of the 20th century, and by the notion of relaxed problem and generalized solution (Young [73]).

Trajectory optimization really started with the spectacular achievement done by Pontryagin’s group [71] during the fifties, by stating, for general optimal control problems, nonlocal optimality conditions generalizing those of Weierstrass. This motivated the application to many industrial problems (see the classical books by Bryson and Ho [47], Leitmann [67], Lee and Markus [66], Ioffe and Tihomirov [62]). Since then, various theoretical achievements have been obtained by extending the results to nonsmooth problems, see Aubin [37], Clarke [48], Ekeland [55].

Dynamic programming was introduced and systematically studied by R. Bellman during the fifties. The HJB equation, whose solution is the value function of the (parameterized) optimal control problem, is a variant of the classical Hamilton-Jacobi equation of mechanics for the case of dynamics parameterized by a control variable. It may be viewed as a differential form of the dynamic programming principle. This nonlinear first-order PDE appears to be well-posed in the framework of *viscosity solutions* introduced by Crandall and Lions [50], [51], [49]. These tools also allow to perform the numerical analysis of discretization schemes. The theoretical contributions in this direction did not cease growing, see the books by Barles [39] and Bardi and Capuzzo-Dolcetta [38].

3.2. Trajectory optimization

The so-called *direct methods* consist in an optimization of the trajectory, after having discretized time, by a nonlinear programming solver that possibly takes into account the dynamic structure. So the two main problems are the choice of the discretization and the nonlinear programming algorithm. A third problem is the possibility of refinement of the discretization once after solving on a coarser grid.

In the *full discretization approach*, general Runge-Kutta schemes with different values of control for each inner step are used. This allows to obtain and control high orders of precision, see Hager [59], Bonnans [44]. In an interior-point algorithm context, controls can be eliminated and the resulting system of equation is easily solved due to its band structure. Discretization errors due to constraints are discussed in Dontchev et al. [54]. See also Malanowski et al. [68].

In the *indirect* approach, the control is eliminated thanks to Pontryagin's maximum principle. One has then to solve the two-points boundary value problem (with differential variables state and costate) by a single or multiple shooting method. The questions are here the choice of a discretization scheme for the integration of the boundary value problem, of a (possibly globalized) Newton type algorithm for solving the resulting finite dimensional problem in \mathbb{R}^n (n is the number of state variables), and a methodology for finding an initial point.

For state constrained problems or singular arcs, the formulation of the shooting function may be quite elaborate [42], [43], [36]. As initiated in [58], we focus more specifically on the handling of discontinuities, with ongoing work on the geometric integration aspects (Hamiltonian conservation).

3.3. Hamilton-Jacobi-Bellman approach

This approach consists in calculating the value function associated with the optimal control problem, and then synthesizing the feedback control and the optimal trajectory using Pontryagin's principle. The method has the great particular advantage of reaching directly the global optimum, which can be very interesting when the problem is not convex.

Characterization of the value function >From the dynamic programming principle, we derive a characterization of the value function as being a solution (in viscosity sense) of an Hamilton-Jacobi-Bellman equation, which is a nonlinear PDE of dimension equal to the number n of state variables. Since the pioneer works of Crandall and Lions [50], [51], [49], many theoretical contributions were carried out, allowing an understanding of the properties of the value function as well as of the set of admissible trajectories. However, there remains an important effort to provide for the development of effective and adapted numerical tools, mainly because of numerical complexity (complexity is exponential with respect to n).

Numerical approximation for continuous value function Several numerical schemes have been already studied to treat the case when the solution of the HJB equation (the value function) is continuous. Let us quote for example the Semi-Lagrangian methods [57], [56] studied by the team of M. Falcone (La Sapienza, Rome), the high order schemes WENO, ENO, Discrete galerkin introduced by S. Osher, C.-W. Shu, E. Harten [60], [61], [61], [69], and also the schemes on nonregular grids by R. Abgrall [35], [34]. All these schemes rely on finite differences or/and interpolation techniques which lead to numerical diffusions. Hence, the numerical solution is unsatisfying for long time approximations even in the continuous case.

One of the (nonmonotone) schemes for solving the HJB equation is based on the Ultrabee algorithm proposed, in the case of advection equation with constant velocity, by Roe [72] and recently revisited by Després-Lagoutière [53], [52]. The numerical results on several academic problems show the relevance of the antidiffusive schemes. However, the theoretical study of the convergence is a difficult question and is only partially done.

Optimal stochastic control problems occur when the dynamical system is uncertain. A decision typically has to be taken at each time, while realizations of future events are unknown (but some information is given on their distribution of probabilities). In particular, problems of economic nature deal with large uncertainties (on prices, production and demand). Specific examples are the portfolio selection problems in a market with risky

and non-risky assets, super-replication with uncertain volatility, management of power resources (dams, gas). Air traffic control is another example of such problems.

Nonsmoothness of the value function. Sometimes the value function is smooth (e.g. in the case of Merton's portfolio problem, Oksendal [74]) and the associated HJB equation can be solved explicitly. Still, the value function is not smooth enough to satisfy the HJB equation in the classical sense. As for the deterministic case, the notion of viscosity solution provides a convenient framework for dealing with the lack of smoothness, see Pham [70], that happens also to be well adapted to the study of discretization errors for numerical discretization schemes [63], [40].

Numerical approximation for optimal stochastic control problems. The numerical discretization of second order HJB equations was the subject of several contributions. The book of Kushner-Dupuis [64] gives a complete synthesis on the Markov chain schemes (i.e Finite Differences, semi-Lagrangian, Finite Elements, ...). Here a main difficulty of these equations comes from the fact that the second order operator (i.e. the diffusion term) is not uniformly elliptic and can be degenerated. Moreover, the diffusion term (covariance matrix) may change direction at any space point and at any time (this matrix is associated the dynamics volatility).

For solving stochastic control problems, we studied the so-called Generalized Finite Differences (GFD), that allow to choose at any node, the stencil approximating the diffusion matrix up to a certain threshold [46]. Determining the stencil and the associated coefficients boils down to a quadratic program to be solved at each point of the grid, and for each control. This is definitely expensive, with the exception of special structures where the coefficients can be computed at low cost. For two dimensional systems, we designed a (very) fast algorithm for computing the coefficients of the GFD scheme, based on the Stern-Brocot tree [45].

4. Application Domains

4.1. Fuel saving by optimizing airplanes trajectories

We have a collaboration with the startup Safety Line on the optimization of trajectories for civil aircrafts. Key points include the reliable identification of the plane parameters (aerodynamic and thrust models) using data from the flight recorders, and the robust trajectory optimization of the climbing and cruise phases.

4.2. Hybrid vehicles

We have a collaboration with IFPEN on the energy management for hybrid vehicles. A significant direction is the analysis and classification of traffic data.

4.3. Energy production planning

We work with colleagues from U. Chile, in the framework of Inria Chile, on the management of electricity production and storage for a microgrid.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

- B. Heymann received a Siebel Scholar fellowship from the Siebel foundation. These fellowships are given to top graduate students of partner institutions, namely here the Ecole Polytechnique. See the [List of Siebel Scholars](#)

6. New Software and Platforms

6.1. BOCOP

Boite à Outils pour le Contrôle OPTimal

KEYWORDS: Energy management - Numerical optimization - Biology - Identification - Dynamic Optimization - Transportation

FUNCTIONAL DESCRIPTION

Bocop is an open-source toolbox for solving optimal control problems, with collaborations with industrial and academic partners. Optimal control (optimization of dynamical systems governed by differential equations) has numerous applications in transportation, energy, process optimization, energy and biology. Bocop includes a module for parameter identification and a graphical interface, and runs under Linux / Windows / Mac.

- Participants: Joseph Frédéric Bonnans, Pierre Martinon, Olivier Tissot and Benjamin Heymann
- Contact: Pierre Martinon
- URL: <http://bocop.org>

6.2. Bocop Avion

KEYWORDS: Optimization - Aeronautics

FUNCTIONAL DESCRIPTION

Optimize the climb speeds and associated fuel consumption for the flight planning of civil airplanes.

- Participants: Joseph Frédéric Bonnans, Pierre Martinon, Stéphan Maindrault, Cindie Andrieu, Pierre Jouniaux and Karim Tekkal
- Contact: Pierre Martinon

6.3. Bocop HJB

- Participants: Joseph Frédéric Bonnans, Pierre Martinon, Benjamin Heymann and Olivier Tissot
- Contact: Joseph Frédéric Bonnans
- URL: <http://bocop.org>

7. New Results

7.1. Optimal control of ordinary differential equations

7.1.1. *Periodic optimal controls for the Purcell microswimmer*

Participant: Pierre Martinon.

We investigate in [31] some geometric and numerical aspects related to optimal control problems for the so-called Purcell Three-link swimmer, in which the cost to minimize represents the energy consumed by the swimmer. More precisely, we focus on the periodic aspect of optimal trajectories and controls. Linearizing the control system along a reference extremal, we estimate the conjugate points, which play a crucial role for the second order optimality conditions. With techniques imported by the sub-Riemannian geometry, we also show that the nilpotent approximation of the system provides a model which is integrable, obtaining explicit expressions in terms of elliptic functions. This approximation allows to compute optimal periodic controls for small deformations of the body. Numerical simulations are presented using HamPath and Bocop codes. A first paper was submitted in October 2015.

7.1.2. *Study of optimal health insurance policies*

Participant: Pierre Martinon.

In collaboration with the Economy department of Ecole Polytechnique, we analyze the design of an optimal medical insurance contract under ex post moral hazard, i.e., when illness severity cannot be observed by insurers and policyholders may exaggerate their health expenditures. This problem is reformulated in the optimal control framework, and we study the possible existence of deductibles or bunching phenomena in optimal contracts. A paper will be submitted in early 2016.

7.2. Optimal control of partial differential equations

7.2.1. Local minimization algorithms for dynamic programming equations

Participant: Axel Kröner.

The numerical realization of the dynamic programming principle for continuous-time optimal control leads to nonlinear Hamilton-Jacobi-Bellman equations which require the minimization of a nonlinear mapping over the set of admissible controls. This minimization is often performed by comparison over a finite number of elements of the control set. In this paper we demonstrate the importance of an accurate realization of these minimization problems and propose algorithms by which this can be achieved effectively. The considered class of equations includes nonsmooth control problems with l_1 -penalization which lead to sparse controls. See the reprint [28].

7.2.2. Suboptimal feedback control of PDEs by solving HJB equations on adaptive sparse grids

Participant: Axel Kröner.

An approach to solve finite time horizon sub-optimal feedback control problems for partial differential equations is proposed by solving dynamic programming equations on adaptive sparse grids. The approach is illustrated for the wave equation. A semi-discrete optimal control problem is introduced and the feedback control is derived from the corresponding value function. The value function can be characterized as the solution of an evolutionary Hamilton-Jacobi Bellman (HJB) equation which is defined over a state space whose dimension is equal to the dimension of the underlying semi-discrete system. Besides a low dimensional semi-discretization it is important to solve the HJB equation efficiently to address the curse of dimensionality. We propose to apply a semi-Lagrangian scheme using spatially adaptive sparse grids. Sparse grids allow the discretization of the value functions in (higher) space dimensions since the curse of dimensionality of full grid methods arises to a much smaller extent. For additional efficiency an adaptive grid refinement procedure is explored. We present several numerical examples studying the effect the parameters characterizing the sparse grid have on the accuracy of the value function and the optimal trajectory. See the report [27].

7.2.3. Numerical approximation of level set power mean curvature flow

Participant: Axel Kröner.

In this paper we investigate the numerical approximation of a variant of the mean curvature flow. We consider the evolution of hypersurfaces with normal speed given by H^k , $k \geq 1$, where H denotes the mean curvature. We use a level set formulation of this flow and discretize the regularized level set equation with finite elements. In a previous paper we proved an a priori estimate for the approximation error between the finite element solution and the solution of the original level set equation. We obtained an upper bound for this error which is polynomial in the discretization parameter and the reciprocal regularization parameter. The aim of the present paper is the numerical study of the behavior of the evolution and the numerical verification of certain convergence rates. We restrict the consideration to the case that the level set function depends on two variables, i.e. the moving hypersurfaces are curves. Furthermore, we confirm for specific initial curves and different values of k that the flow improves the isoperimetrical deficit. See the report [29].

7.3. Finance and stochastic control

7.3.1. Second order Pontryagin's principle for stochastic control problems

Participant: Frédéric Bonnans.

In this Hal reprint [25], we discuss stochastic optimal control problems whose volatility does not depend on the control, and which have finitely many equality and inequality constraints on the expected value of functions of the final state, as well as control constraints. The main result is a proof of necessity of some second order optimality conditions involving Pontryagin multipliers.

7.3.2. On the convergence of the Sakawa-Shindo algorithm in stochastic control

Participant: Frédéric Bonnans.

In the accepted paper [32], we analyze an algorithm for solving stochastic control problems, based on Pontryagin's maximum principle, due to Sakawa and Shindo in the deterministic case and extended to the stochastic setting by Mazliak. We assume that either the volatility is an affine function of the state, or the dynamics are linear. We obtain a monotone decrease of the cost functions as well as, in the convex case, the fact that the sequence of controls is minimizing, and converges to an optimal solution if it is bounded. In a specific case we interpret the algorithm as the gradient plus projection method and obtain a linear convergence rate to the solution.

7.3.3. *Optimal multiple stopping problems*

Participant: Frédéric Bonnans.

In the paper [13] we extend some results by Carmona and Touzi [8], who studied an optimal multiple stopping time problem in a market where the price process is continuous. We generalize their results when the price process is allowed to jump. Also, we generalize the problem associated to the valuation of swing options to the context of jump diffusion processes. We relate our problem to a sequence of ordinary stopping time problems. We characterize the value function of each ordinary stopping time problem as the unique viscosity solution of the associated Hamilton–Jacobi–Bellman variational inequality. In the paper [14] we deal with numerical solutions to an optimal multiple stopping problem. The corresponding dynamic programming (DP) equation is a variational inequality satisfied by the value function in the viscosity sense. The convergence of the numerical scheme is shown by viscosity arguments. An optimal quantization method is used for computing the conditional expectations arising in the DP equation. Numerical results are presented for the price of swing option and the behavior of the value function.

7.4. Electricity production

7.4.1. *Equilibria over energy markets*

Participant: Benjamin Heymann.

Motivated by electricity markets we introduce in this paper a general network market model, in which agents are located on the nodes of a graph, a traded good can travel from one place to another through edges considering quadratic losses. An independent operator has to match locally production and demand at the lowest expense. As argued in our previous paper “Cost-minimizing regulations for a wholesale electricity market” this setting is relevant to describe some real electricity markets, pricing behavior and market power coming from the fact that generators can bid above their true value. In a general setting of many distributed generator agents connected by a transmission network, bidding piece-wise linear cost functions, we propose a pricing optimal mechanism model to reduce market power. Our main results are the expression of the optimal mechanism design, two algorithms for the allocation problem and market power estimations. To deduce these nice properties, we intensively use convex analysis and some monotone behaviors of the set-valued maps involved. Furthermore, these algorithms make it possible to numerically compute a Nash equilibrium for the procurement auction, which is important to compare the optimal mechanism and the standard auction setting. Finally, we also show some interesting examples. In the continuation of this work, we introduce a class of bidding games for which we prove the existence of a Nash equilibrium. We give a sufficient condition for uniqueness, propose a numerical scheme to compute the extreme Nash Equilibria and show that the equilibrium strategies are convex for a subclass of games. We apply this framework to electricity auctions.

7.4.2. *Energy management for a micro-grid*

Participants: Frédéric Bonnans, Benjamin Heymann, Pierre Martinon, Olivier Tissot.

We study in [33] the energy management problem for a microgrid including a diesel generator and a photovoltaic plant with a battery storage system. The objective is to minimize the total operational cost over a certain timeframe, primarily the diesel consumption, while satisfying a prescribed power load. After reformulation, the decision variables can be reduced to the charging /discharging power for the battery system. We take into account the switching cost for the diesel generator, the non-convex objective, and the long-term aging of the batteries. We solve this problem using a continuous optimal control framework, with both a direct transcription method (time discretization) and a Dynamic Programming method (Hamilton Jacobi Bellman). This project is a collaboration between team COMMANDS (Inria Saclay, France) and Centro de Energia (Universidad de Chile, Chile). Ongoing works include more refined battery aging models, and modeling the stochastic nature of the photovoltaic power and power load.

7.5. Energy management in transport

7.5.1. Energy management for an hybrid vehicle

Participants: Florine Bleuse, Frédéric Bonnans, Pierre Martinon.

In the framework of the PhD thesis of F.Bleuse, 'Optimal control and robustness for rechargeable hybrid vehicles'. The study is focused on the so-called parallel architecture, with both the thermal and electric engines able to move the vehicle. The main axis is to optimize the use of the thermal engine. We started to develop a methodology with two time scales for solving the problem of computing a feedback control.

7.5.2. Collaboration with the startup Safety Line

Participants: Frédéric Bonnans, Pierre Martinon, Olivier Tissot.

We pursue our collaboration with Safety Line, using more refined atmospheric models (including for instance predicted wind data). Future works include high performance optimization for the cruise phase as well as analyzing the validity of the parameter estimation performed with the data from the flight recorders.

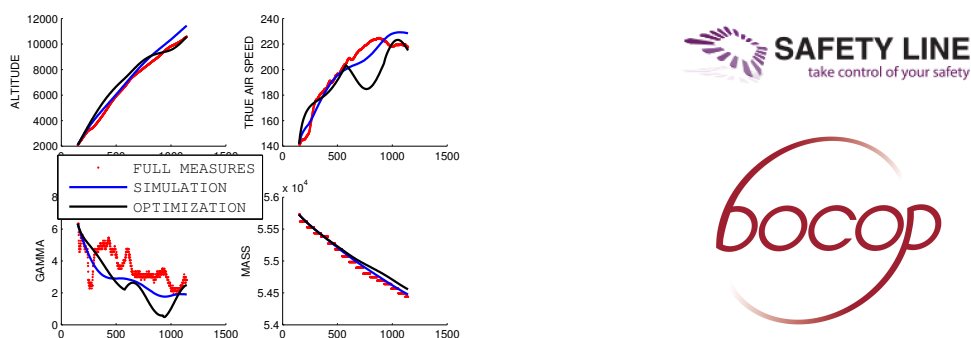


Figure 1. Parameter identification and trajectory optimization

8. Bilateral Contracts and Grants with Industry

8.1. Transportation

8.1.1. IFPEN

In the framework of the PhD thesis of F.Bleuse, 'Optimal control and robustness for rechargeable hybrid vehicles'. The study is focused on the so-called parallel architecture, with both the thermal and electric engines able to move the vehicle. The main axis is to optimize the use of the thermal engine.

8.1.2. Safety Line

(a startup in aeronautics), research and transfer contract, optimization of fuel consumption for civil planes. A first part is devoted to the identification of the aerodynamic and thrust characteristics of the plane, using recorded flight data. A second part is optimizing the fuel consumption during the climb phase.

9. Partnerships and Cooperations

9.1. Regional Initiatives

- Axel Kröner, Frederic Bonnans: “Optimal control of partial differential equations using parameterizing manifolds, model reduction, and dynamic programming”. Foundation Mathématique Jacques Hadamard/PGMO

9.2. International Initiatives

9.2.1. Inria International Labs

Participation to the Inria Chile laboratory.

9.3. International Research Visitors

9.3.1. Visits of International Scientists

9.3.1.1. Internships

- Justina Jianatti (PhD student, U. Rosario, Argentina). Numerical algorithms for stochastic control problems. Supervised by F. Bonnans.
- Mandy Huo (now PhD at Caltech, USA): International internship of École Polytechnique on aspects of optimal control of bilinear equation. Supervised by A. Kröner.

9.3.2. Visits to International Teams

9.3.2.1. Explorer programme

Kröner Axel

Date: Jul 2015 - Aug 2015

Institution: [University of California, Los Angeles](#) (United States)

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

- Axel Kröner (chair), Frederic Bonnans: Workshop on “Optimal Control of Partial and Ordinary Differential Equations”, Palaiseau, November 16-17
- Axel Kröner: Minisymposium on “Optimal Control and Hamilton-Jacobi Bellman Equations: Numerical Methods and Applications”

10.1.1.2. Member of the organizing committees

- F. Bonnans: PGMO days, Oct. 27-28, Ensta, Palaiseau.

10.1.2. Scientific events selection

10.1.2.1. Member of the conference program committees

- F. Bonnans: XII International Seminar on Optimization and Related Areas (ISORA), Lima, Peru, 5-9 October 2015.
16th IFAC Workshop Control Applications of Optimization (CAO'2015) Garmisch-Partenkirchen, Germany, Oct. 6-9, 2015.
EUROPT Workshop on Advances in Continuous Optimization, July 8-10, 2015, Edinburgh.

10.1.2.2. Organization of sessions

- A. Kröner (with D. Kalise (RICAM)): Minisymposium on "Optimal Control and Hamilton-Jacobi Bellman Equations: Numerical Methods and Applications. 27 th IFIP TC7 Conference 2015 on System Modelling and Optimization. SophiaTech Campus Sophia Antipolis, France, June 29 - July 3, 2015

10.1.3. Journal

10.1.3.1. Editorial boards

- F. Bonnans is Corresponding Editor of "ESAIM:COCV" (Control, Optimization and Calculus of Variations), and Associate Editor of "Applied Mathematics and Optimization", "Optimization, Methods and Software", and "Series on Mathematics and its Applications, Annals of The Academy of Romanian Scientists".

10.1.3.2. Reviewer - Reviewing activities

Reviews for major journals in the field such as Applied Mathematics and Optimization, Automatica, Journal of Optimization Theory and Applications the SIAM J. Optimization, SIAM J. Control and Optimization.

10.1.4. Leadership within the scientific community

- F. Bonnans: member of the PGMO board (Gaspard Monge Program for Optimization and Operations Research, EDF-FMJH).
- F. Bonnans: member of the Broyden Prize committee (from the Journal Optimization Methods and Software).

10.1.5. Research administration

- F. Bonnans: member of the Institut carnot Inria commission, and of the Inria-Saclay commission for "Technological development actions" (ADT).

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

- Master :
F. Bonnans: Numerical analysis of partial differential equations arising in finance and stochastic control, 24h, M2, Ecole Polytechnique and U. Paris 6, France.
F. Bonnans: Optimal control, 15h, M2, Optimization master (U. Paris-Saclay) and Ensta, France.
F. Bonnans : Stochastic optimization, 15h, M2, Optimization master (U. Paris-Saclay), France.

E-learning

Pedagogical resources: F. Bonnans, several lecture notes on the page
<http://www.cmap.polytechnique.fr/~bonnans/notes.html>

10.2.2. Supervision

- PhD in progress : Cédric Rommel, Data exploration for the optimization of aircraft trajectories. Started November 2015, F. Bonnans and P. Martinon, CIFRE fellowship (Safety Line).

- PhD in progress : Benjamin Heymann, Dynamic optimization with uncertainty; application to energy production. Started October 2013, F. Bonnans, Polytechnique fellowship.
- PhD: Florine Bleuse, Optimal control and robustness for rechargeable hybrid vehicles. Started October 2014, stopped September 2015. F. Bonnans and P. Martinon, IFPEN fellowship.
- PhD: Nicolas Gréville, Numerical methods for solving stochastic equilibrium problems; application to energy markets. Started January 2013, stopped December 2015, F. Bonnans, CIFRE fellowship (EDF R & D).
- PhD: Cristopher Hermosilla, Optimal control problems on well-structured domains and stratified feedback controls, ENSTA ParisTech, February 2015, F. Jean, H. Zidani. <https://hal.inria.fr/tel-01128691> [11][cite:picarelli:tel-01145588]
- PhD: A. Picarelli, On some stochastic control problems with state constraints, ENSTA ParisTech, April 2015, H. Zidani.

10.2.3. Juries

Various PhD juries in France.

10.3. Popularization

- F. Bonnans: article on 'Optimal Control' for the Encyclopédie des sciences de l'ingénieur [30].
- F. Bonnans and P. Martinon: Inria-industry day on energetic transition, June 12, 2015. Common stand with Safety Line on energy savings by optimization aircraft trajectories.
- B. Heymann: talk at the Workshop on open power systems (WOPS), Oct. 16, 2015, Institut des systèmes complexes, Paris .

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