INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team BIPOP

Modeling, Simulating, Controlling Non-Regular Dynamical Systems

Rhône-Alpes

THEME NUM

Activity Report

2006

Table of contents

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2. Overall Objectives

2.1. Overall Objectives

Generally speaking, this project deals with nonregular systems, control, modelling and simulation, with emphasis on

- dynamic systems, mostly mechanical systems with unilateral constraints and Coulomb friction, but also electrical circuits with ideal diodes and transistors Mos, etc;
- numerical methods for nonsmooth optimization, and more generally the connection between continuous and combinatorial optimization.

3. Scientific Foundations

3.1. Dynamic non-regular systems

Keywords: *analysis*, *complementarity*, *control*, *convex analysis*, *impacts*, *mechanical systems*, *modeling*, *simulation*, *unilateral constraints*.

Dynamical systems (we limit ourselves to finite-dimensional ones) are said to be *non-regular* whenever some nonsmoothness of the state arises. This nonsmoothness may have various roots: for example some outer impulse, entailing so-called *differential equations with measure*. An important class of such systems can be described by the complementarity system

$$\left\{\begin{array}{l} \dot{x} = f(x, u, \lambda)\,, \\ 0 \leq y \perp \lambda \geq 0\,, \\ g(y, \lambda, x, u, t) = 0\,, \\ \text{re-initialization law of the state } x(\cdot)\ , \end{array}\right. \tag{1}$$

where $\perp$ denotes orthogonality; u is a control input. Now (1) can be viewed from different angles.

- Hybrid systems: it is in fact natural to consider that (1) corresponds to different models, depending whether $y_i = 0$ or $y_i > 0$ (y_i being a component of the vector y). In some cases, passing from one mode to the other implies a jump in the state x; then the continuous dynamics in (1) may contain distributions.
- Differential inclusions: $0 \leq y \perp \lambda \geq 0$ is equivalent to $-\lambda \in \mathrm{N}_K(y)$, where K is the nonnegative orthant and $\mathrm{N}_K(y)$ denotes the normal cone to K at y. Then it is not difficult to reformulate (1) as a differential inclusion.
- Dynamic variational inequalities: such a formalism reads as $\langle \dot{x}(t) + F(x(t), t), v - x(t)\rangle \geq 0$ for all $v \in K$ and $x(t) \in K$, where K is a nonempty closed convex set. When K is a polyhedron, then this can also be written as a complementarity system as in (1).

Thus, the 2nd and 3rd lines in (1) define the modes of the hybrid systems, as well as the conditions under which transitions occur from one mode to another. The 4th line defines how transitions are performed by the state x. There are several other formalisms which are quite related to complementarity. A tutorial-survey paper has been published [2], whose aim is to introduce the dynamics of complementarity systems and the main available results in the fields of mathematical analysis, analysis for control (controllability, observability, stability), and feedback control.

3.2. Nonsmooth optimization

Keywords: *Lagrangian relaxation*, *combinatorial optimization*, *convexity*, *numerical algorithm*, *optimization*.

Here we are dealing with the minimization of a function f (say over the whole space R^n), whose derivatives are discontinuous. A typical situation is when f comes from dualization, if the primal problem is not strictly convex – for example a large-scale linear program – or even nonconvex – for example a combinatorial optimization problem. Also important is the case of spectral functions, where $f(x) = F(\lambda(A(x)))$, A being a symmetric matrix and λ its spectrum.

For these types of problems, we are mainly interested in developing efficient resolution algorithms. Our basic tool is bundling (Chap. XV of [8]) and we act along two directions:

- To explore application areas where nonsmooth optimization algorithms can be applied, possibly after some tayloring. A rich field of such application is combinatorial optimization, with all forms of relaxation [11], [10].
- To explore the possibility of designing more sophisticated algorithms. This implies an appropriate generalization of second derivatives when the first derivative does not exist, and we use advanced tools of nonsmooth analysis, for example [12].

4. Application Domains

4.1. Application Domains

Many systems (either actual or abstract) can be represented by (1). Some typical examples are:

- Mechanical systems with unilateral constraints and dry friction (the biped robot is a typical example), including kinematic chains with slack, phenomena of liquid slosh, etc.
- Electrical circuits with ideal diodes and/or transistors MOS.
- Optimal control with constraints on the state, closed loop of a system controlled by an MPC algorithm, etc.

This class of models is not too large (to allow thorough studies), yet rich enough to include many applications. This goes in contrast to a study of general hybrid systems. Note for example that (1) is a “continuous” hybrid system, in that the continuous variables x and u prevail in the evolution (there is no discrete control to commute from a mode to the other: only the input u can be used). Let us cite some specific applications.

4.1.1. Electronic circuits

– either integrated on a single substrate or as a set of components on a board – are very often a complex assembly of many basic components with non linear characteristics. The IC technologies now allow the integration of hundreds of millions of transistors switching at GHz frequencies on a die of 1cm^2. It is out of question to simulate a whole such IC with standard tools such as the SPICE simulator. We currently work on a dedicated plug-in able to simulate a whole circuit comprising various components, some modelled in a nonsmooth way.

4.1.2. Walking robots

– for example hexapods – possess definite advantages over the rolling ones whenever the ground is not plane or free: clearing obstacles is easier, holding on the ground is lighter, adaptivity is improved. However, if the working environment of the system is adapted to man, the biped technology must be preferred, to preserve good displacement abilities without modifying the environment. This explains the interest displayed by the international community in robotics toward humanoid systems, whose aim is to back man in some of his activities, professional or others. For example, a certain form of help at home to disabled persons could be done by biped robots, as they are able to move without any special adaptation of the environment.

4.1.3. Virtual reality

Here, a major issue is the representation of real phenomena and the fine control of the model behind this. In particular, the interaction between objects, and therefore the treatment of contact, friction and impacts, is crucial. This treatment is usually decomposed into two tasks. The first one, which corresponds to the geometric detection of the interaction, is now carried out in a very efficient way for simple geometric primitives. The second task, numerical, constitutes the core of the collaboration between the Siames (Irisa/Rennes) and Bipop projects. Our main aim is to bridge the gap between the know-how of Bipop in nonsmooth mechanics and the know-how of Siames in virtual reality applications.

4.1.4. Optimization

exists in virtually all economic sectors. Simulation tools can be used to optimize the system they simulate. Another domain is parameter *identification* (Idopt or Estime teams), where the deviation between measurements and theoretical predictions must be minimized. Accordingly, giving an exhaustive list of applications is impossible. Some domains where Inria has been implied in the past, possibly through the former Promath and Numopt teams are: production management, geophysics, finance, molecular modeling, robotics, networks, astrophysics, crystallography, ...Our current applicative activity includes: the management of electrical production, deterministic or stochastic, the design and operation of telecommunication networks.

5. Software

5.1. Nonsmooth dynamics

In the framework of the European project Siconos, Bipop is the leader of the Work Package 2 (WP2), dedicated to the numerical methods and the software design for nonsmooth dynamical systems. The aim of this work is to provide a common platform for the simulation, modeling, analysis and control of abstract nonsmooth dynamical systems. Besides usual quality attributes for scientific computing software, we want to provide a common framework for various scientific fields, to be able to rely on the existing developments (numerical algorithms, description and modeling software), to support exchanges and comparisons of methods, to disseminate the know-how to other fields of research and industry, and to take into account the diversity of users (end-users, algorithm developers, framework builders) in building expert interfaces in Python and end-user front-end through Scilab.

After the requirement elicitation phase, the Siconos Software project has been divided into 5 work packages which are identified to software products:

1. *Siconos/Numerics* This library contains a set of numerical algorithms, already well identified, to solve non smooth dynamical systems. This library is written in low-level languages (C,F77) in order to ensure numerical efficiency and the use of standard libraries (Blas, Lapack, ...)
2. *Siconos/Kernel(Engine + Front-End)* The Engine is an object-oriented structure (C++) for modeling and simulation of abstract dynamical systems. The Front-End is the driver interface of the Engine thanks to two types of API's. The first one is an API in C++, interfaced in Python for scripting uses. The second API, in C, will be interfaced with Scilab for a more user-friendly platform.
3. *Siconos/Analysis* This part is devoted to the stability and bifurcation analysis of nonsmooth dynamical systems.
4. *Siconos/Control* This part is devoted to the implementation of control strategies of non smooth dynamical systems.
5. *Siconos/*IMSE The final product is an Integrated modeling and Simulation Environment dedicated to applied nonsmooth problems.

Further informations may be found at http://siconos.gforge.inria.fr/

5.2. Humanoid motion analysis and simulation

The HuMAnS toolbox offers tools for the modelling, control and analysis of humanoid motion, be it of a robot or a human. It is a C/C++/Scilab/Maple-based set of integrated tools for the generation of dynamical models of articulated bodies with unilateral contact and friction, their simulation with an event-driven integration scheme, their 3D visualization, the computation of stability measures, optimal positions and trajectories, the generation of control laws and observers, the reconstruction of movements from different sensing systems.

5.3. Optimization

Essentially two possibilities exist to distribute our optimization software: library programs (say Modulopt codes), communicated either freely or not, depending on what they are used for, and on the other hand specific software, developed for a given application.

The following optimization codes have been developed in the framework of the former Promath project.

5.3.1. Code M1QN3

Optimization without constraints for problems with many variables ($n \geq 10^3$, has been used for $n = 10^6$). Technically, uses a limited-memory BFGS algorithm with Wolfe's line-search (see Chap. 4 of [1] for the terminology).

5.3.2. Code M2QN1

Optimization with simple bound-constraints for (small) problems: D is a parallelotope in R^n. Uses BFGS with Wolfe's line-search and active-set strategy.

5.3.3. Code N1CV2

Minimization without constraints of a convex nonsmooth function by a proximal bundle method (Chap. XV of [8], Chap. 9 of [1]).

5.3.4. Modulopt

In addition to codes such as above, the Modulopt library contains application problems, synthetic or from the real world. It is a field for experimentation, functioning both ways: to assess a new algorithm on a set of test-problems, or to select among several codes one best suited to a given problem.

6. New Results

6.1. Modeling

6.1.1. Higher-order Moreau's sweeping process

Participants: Vincent Acary, Bernard Brogliato.

The sweeping process is a specific differential inclusion introduced by J.J. Moreau in 1971, whose righthand side is a normal cone to a convex set (first order, absolutely continuous solutions), or a normal cone to a tangent cone to a convex set (second order, measure solutions). In [15] we extend it to an arbitrary order by defining a specific sequence of tangent cones, together with a canonical state space representation which makes the zero-dynamics explicitly appear. The solutions are in a special class of distributions, generated by functions of special locally bounded variation. The well-posedness is proved, as well as useful properties of ths solutions (like dissipativity, jump rules). A numerical scheme is introduced, and its properties are studied carefully. This formalism allows us to give a meaning to the dynamics of linear complementarity systems with relative degree larger than 2. The work in [31] consists first of showing that dissipative complementarity systems can be, via a suitable change of coordinates, recast into perturbed Moreau's sweeping process. Then one can take advantage of the well-posedness studies of perturbed sweeping processes, to build existence and uniqueness results for such systems.

6.1.2. Modeling and well-posedness of electrical circuits

Participant: Bernard Brogliato.

Nonsmooth electrical circuits are made of resistors, capacitors, inductors, and piecewise linear elements like ideal diodes and thyristors. We show in [16] that such dynamical systems can benefit a lot from the tools of convex and nonsmooth analysis introduced by J.J. Moreau and P.G. Panagiotopoulos. A general formalism is introduced, which extends the work initiated in [41]. In [30] the well-posedness of static nonsmooth circuits is studied, relying on the use of recession tools that defined a new class of problems that we call semi-complementarity problems. This is shown to enable one to study the existence and uniqueness of solutions of a large class of variational inequalities arising in electronics.

6.1.3. Simulation of electrical circuits

Participants: Vincent Acary, Bernard Brogliato, Pascal Denoyelle, Tomasz Toczek.

We have started last year a study of electrical circuits, modeled as non-smooth dynamical systems. After the first successful tests carried last year on elementary circuits, various other circuits have been modelled as non-smooth systems and simulated with the SICONOS software. The modelling activity was focused mainly on MOS transistors; this was the specific work of Tomasz Toczek. Thanks to this model, a standard CMOS structure (an inverter chain) was successfully simulated with interesting results as compared to SPICE – see [32]. Other circuits pertaining to the mixed-mode (analog-digital) field were also simulated with favorable results.

A common project named “VAL-AMS”, dedicated to the high confidence Validation of Analog and Mixed Signal Circuits, has been setup jointly with Verimag laboratory and LMC, in the framework of ANR’s call for projects on safety of computer systems (SETIN). INRIA’s contribution will be the development of an electrical circuit simulator.

6.1.4. Nonsmooth fracture dynamics

Participant: Vincent Acary.

This joint work with Y. Monerie (IRSN Cadarache) is devoted to the understanding, prediction and numerical simulation of dynamic fracture for a wide variety of materials and structures. 0ur main contribution concerns the prediction of the entire fracture process from crack initiation, growth, propagation, and final rupture, to post-fracture behavior such as unilateral contact and dry friction interactions between the fragments created after fracture. The new Non-Smooth Fracture Dynamics (NSFD) approach presented in [29] is thus based on three main features: a) a surface-volumetric multibody approach using mixed boundary conditions between each volumetric finite elements and/or rigid bodies; b) the development of a generic formulation of the cohesive zone models dedicated to a wide variety of materials and physical phenomena, and incorporating unilateral contact and Coulomb’s dry friction; and c) a specific nonsmooth dynamical framework based on measure differential inclusions and an associated *implicit* time–integration scheme allowing the numerical treatment of nonsmooth events such as impacts due to unilateral constraints.

6.2. Optimization

6.2.1. Cutting planes in combinatorial optimization

Participant: Florent Cadoux.

Now that the basic theory [40], [42] is well-understood, our aim is to derive constructive algorithms to generate good cuts, with special emphasis on the disjunctive case (i.e. separate a point from the convex hull of two polyhedra). We have characterized in [36] the reverse polar (i.e. the set of cutting planes) for a disjunction, as well as the deepest cut seen in the dual. This allows the use of Wolfe’s variant [45] of quadratic programming to construct facet-defining cuts. The feasibility and appraisal of this latter approach is currently under study.

6.2.2. A bundle variant suited to column generation

Participant: Claude Lemaréchal.

In many combinatorial problems amenable to column generation, the master consists in minimizing a linear function subject to a constraint of the type $\sigma(u) \leqslant 1$, where σ is convex positively homogeneous (so that $u = 0$ is a natural Slater point). With K.C. Kiwiel, from Warsaw, we have developed in [34] a constrained bundle variant with no penalty function; instead, a mechanism generates feasible points. Besides, the subproblems can be solved inaccurately – a very useful facility. The approach is illustrated on a variety of cutting-stock problems.

6.2.3. Optimal trajectory generation for industrial robot

Participants: Matthieu Guilbert, Pierre-Brice Wieber.

Recall that this work is done with Staübli SCA, Faverges (Luc Joly).

First, we have worked on decomposing our optimization problem using a ressource decomposition strategy. This decomposition allowed us to integrate efficiently in a robot controller the algorithm that had been developed during the last two years and now described in two articles [27], [26]. Secondly, we have worked on optimizing the velocity profile of a robot trajectory on line; the algorithm is currently being tested.

We have also derived a strategy, based on Bellman’s optimality principle, to generate optimal velocity profiles on line: at each instant on the trajectory, we perform a few iterations of the optimization algorithm and send the (suboptimal) control to the system as soon as it needs it. The resulting mechanism is still in construction.

Besides, we have written an engineer-oriented synthesis of nonlinear optimization methods and Guilbert's thesis is now complete; see [33], [14].

6.2.4. Telecommunication networks

Participants: Claude Lemaréchal, Georges Petrou.

Our activity with FT R&D has concretized in two directions.

Robust network design. We studied a model to minimize the unsatisfied demand, subject to a budget constraint on the arc capacities in the network; this yields a min-max-min problem, i.e. something fairly hard [43]. In [38], we defined an algorithm when the uncertainty set of demands is a polyhedron characterized by its extreme points. The case of a polyhedron defined by constraints seems impossible to solve, we are currently designing an approach to compute suboptimal networks, together with lower bounds on the optimal cost.

Quality of service. The problem of routing several commodities in a network while minimizing travel times lends itself to Lagrangian relaxation; see [44] for example. The resulting dual function is the sum of a smooth and a polyhedral term. For the first term, a quadratic approximation is appropriate, and the second can be handled by bundling. Accordingly, we have defined a hybrid bundle-type method to optimize such functions; the results are spectacular, see [35], and also [39] for a similar approach.

6.3. Locomotion analysis

6.3.1. Reconstruction of 3D movements with inertial and/or optical sensors

Participants: Pierre-Brice Wieber, Fabien Jammes.

The problem of reconstructing the 3D movements of a person, based on inertial and/or optical measurements, can be considered as an inverse problem, with the help of a "direct" model of both the biomechanics of the person and the measurement process. This reconstruction can be seen then as a nonlinear least-squares problem with box constraints, which is solved successfully with a classical Gauss-Newton scheme.

6.3.2. Online generation of cyclic trajectories – Application to rehabilitation

Participants: Bernard Espiau, Rodolphe Héliot.

This work is conducted with Christine Azevedo (Lirmm) and Dominique David (Cea-Leti). When controlling postural movements through artificial prosthetic limbs or muscle Functional Electrical Stimulation (FES), an important issue is the enhancement of the interaction of the patient with the artificial system through his valid limb motions. Dealing with gait rehabilitation in stroke patients, we developped a method to monitor the ongoing movement and generate the desired trajectory on the affected leg. To achieve this, we place a sensor on the valid leg, and build a model of the sensor measurement during gait. Since the movement is cyclical, we used a non-linear oscillator model, which can autonomously (i.e. without input) produce a cyclical output. We fit the model parameters by optimization, and build an observer of it. Then, we can "filter" the sensor measurements with our observer: since the observer is adapted to its input, we can be sure that the it will well synchronize. Finally, since the observer is also an oscillator, it is possible to reconstruct the oscillator phase, and generate a desired trajectory according to this phase.
Applied to the rehabilitation issue, this method can be used in different ways:

- provide the stimulation system with discrete inputs that will trigger the muscle.
- generate a desired trajectory for the paratic leg, and synthetize the stimulation sequence with a musculo-skeletal model.

6.3.3. Gait evaluation system

Participants: Bernard Espiau, Rodolphe Héliot.

During a given rehabilitation protocol for stroke patients reeducation, it is of great interest to assess the gait of the patient, to monitor the improvement of the gait. Such evaluation can be achieved through standard tests (Barthel Index, Ashwoth scale, ...) held by the clinicians, or by measuring some gait variables: locomotion speed, symetry. However, such variables need specific equipement to be measured, and required more people around the patient. Our aim is to provide with a gait analysis system which could easily give an objective criteria of gait quality. By placing an accelerometer on the healthy shank, we can measure some helpful variables, as stride gait frequency. We perform a frequency analysis of the accelerometric signal, and exhibit a frequency ratio that shows good correlation with gait speed and symetry. Such an analysis only require a simple system (an accelerometer; today, such sensor can be completely wireless, thus not disturbing the patients' gait); we developped an analysis software that gives an quantitative result right after the measurement. We believe that such a tool could be of great help in rehabilitation centers.

6.4. Software development

6.4.1. HuMAnS toolbox

Participants: Pierre-Brice Wieber, Florence Billet, Florence Boissieux, Remy Mozul, Roger Pissard-Gibollet.

A special emphasis has been put this year on developing a full body biomechanical model of a human with 42 degrees of freedom and algorithms for the estimation of 3D movements as described in § 6.3.1. An interconnection with the Siconos platform for a more extensive simulation of the mechanics with unilateral contact has been undertaken as well.

6.4.2. Platform development

Participants: Vincent Acary, Pascal Denoyelle, Franck Pérignon.

The main achievements for the Siconos platform, presented in [25], are:

- *Siconos/Numerics*
  - the development and validation of the nonsmooth solvers for the frictional contact problem in two- and three-dimensional configurations;
  - the development and the validation of non-smooth solvers for block-structured problems;
  - the improvements of the convergence tests based on Fischer-Bursmeister functions.
- *Siconos/Kernel*.
  - Assessing the portability on various Linux systems; work performed with the help of Philip Naylor, University of Bristol.
  - Time-stepping methods for the fully non linear Lagrangian systems with contact and friction in 2D and 3D.
  - Implementation of an event-driven scheme, developed in a quite general way. Its design and development have indeed been inspired by the VHDL standards for the simulation of discrete-time systems. This design should allow us to couple the Siconos platform with a general discrete event-driven simulator, and to take into account any discrete external event interaction with the platform.
  - Boost Library integration http://www.boost.org/ for the management of the linear algebra objects.
  - New samples developments.
- *Siconos/Front-end*; work carried out by CO1 (mainly F. Pérignon, R. Pissard-Gibollet.)
  - First version of the API/C of the Siconos/Kernel;
  - Updating Python interface and installation;
  - First version of the Scilab interface based on the API/C.

Following the recommendation of the Fifth Technical Review Meeting, an effort has been made on the documentation for users and developers:
– An updated version of the **design and development documentation**. The document, summarized in the Deliverable D2.2, is made of the web pages describing the design and development concepts and the automatically generated documentation of the source codes.
– A **Getting Started Guide** has been written. The goal of the Getting Started Guide is to lead the users through the basic steps required to model and to simulate a NSDS thanks to the platform.
– A new **Installation guide** has been written.
– An **User manual** is in progress. It plays the role of a reference manual and should be based on the Doxygen documentation tools and be generated automatically from the source code. The dissemination of the information inside the project should be avoided using a single source of documentation.
– An **Example manual** is also in progress.
– A draft **Theory Manual**, based on the lecture notes given at the CEA-EDF-INRIA school.

All of this documentation will be available on the Siconos Software Website in html and pdf.

7. Contracts and Grants with Industry

7.1. Contracts and Grants with Industry

– Staübli SCA, contract 16: control of an articulated robot;
– FT R&D, contract 444: robust design of telecommunication networks;

8. Other Grants and Activities

8.1. Other Grants and Activities

– Coordination of the European project Siconos (modeling, SImulation and COntrol of NOnsmooth dynamical Systems, IST 2001-37172), which was an FP5 project from September 2002 to September 2006. See http://siconos.inrialpes.fr.
– ANR Slalom (Système de capteurs et logiciel d'animationn permettant l'observation du mouvement d'un skieur freestyle), RNTL.
– ANR Guidage (Nouvelles stratégies pour le guidage et la commande de systèmes), BLAN NT05-1_43040.
– ANR VAL-AMS (High-confidence validation of analog and mixed signal circuits), SETIN.

9. Dissemination

9.1. Dissemination of software

9.1.1. Siconos platform

The platform has been presented at several meetings: Mathmod conference and Hycon WP3 meeting, CEA-EDF-INRIA summer school, International School on "Topics in nonlinear dynamics", to the Hybrid Element Method project in Lyon, and has been installed on various computers at the University of Bristol. It is now available on the tool repository of WP3 Hycon, where it will be included in the demonstrator site and at the European Embedded Control Institute http://ist-hycon.org/index.php?p=EECI; it will be presented at the forthcoming industrial seminar in Rome.

A new Siconos users' week has been organized in Grenoble, to implement new samples and benchmarks in the platform, to teach its new features, and to get a feedback on the users' needs. Every example of the users could be successfully implemented:

– M. Moeller (CR10): simulation of the wood-pecker toy;
– P. Denoyelle (C01): simulation of half wave rectifier and 4 diode bridge rectifier;
– I. Merillas (CR9): simulation of a buck converter, of a parallel resonant converter, of a boost converter as LCS with sliding mode control; Generalized Discontinuous Conduction Mode (GDCM) in the complementarity formalism (Merillas' PhD thesis, to be defended next February, has a chapter presenting the platform, in particular the routines for analysis, stability, bifurcations, invariant manifolds,...)
– G. Osorio (CR4-AC5): simulation of the cam-follower systems;
– A. Doris (CR8): simulation of an experimental drill-string system with discontinuous friction;
– P. Piiroinen (CR6) and I. Merillas (CR9): bifurcation analysis and domains of attraction of a forced harmonic oscillator;
– F. Pérignon (C01): simulation of a robotic arm;
– S. Nineb and D. Dureisseix (AC2): simulation of a tensegrity structure.

9.1.2. Optimization codes

– N1CV2 at the Univ. of Pisa (wrapper for solver-oracle interface).

9.2. Animation of the scientific community

B. Brogliato is:
– Associate Editor for Automatica (June 1999 to June 2005: Intelligent and Adaptive Systems; since June 2005: Nonlinear Systems and Control)
– Reviewer for Mathematical Reviews since 2001
– Reviewer for ASME Applied Mechanics Reviews since 2001

B. Espiau is a member of
– the Steering Committees of Laas and Lirm,
– the Scientific Committee of JRL-France (Joint Robotics Laboratory),

9.3. Teaching

– UFR IMA, UJF Grenoble (V. Acary: Mathematical models for physics, 48h lecturing);
– UFR Mechanics, UJF Grenoble (V. Acary: Introduction to Femlab, 12h tutoring);
– Ensimag, Grenoble (J. Malick, F. Cadoux: Numerical Optimization, 27h lecturing and tutoring);
– Rank Xerox, Meylan (C. Lemaréchal: Numerical Optimization, 8h lecturing).

9.4. Participation to conferences, seminars

The BIPOP team organized the CEA-EDF-INRIA Summer School "Nonsmooth Dynamical Systems. Analysis, Control, Simulation and Applications"; Rocquencourt, May-June. Other participations were:
– 9th Workshop on Combinatorial Optimization; Aussois, January;
– MATHMOD 2006; Vienna, February (1 presentation);
– CMBBE; Antibes, March (1 presentation);
– FT R&D Optimization seminar; Sophia Antipolis, May (1 presentation);
– ECCM 2006, 3rd European Conference on "Computational Mechanics"; Lisbon, June (1 presentation);
– CORE 40th anniversary; Louvain la Neuve, June (1 presentation);
– 6th AIMS Conference on "Dynamical Systems, Differential Equations and Applications"; Poitiers, June (1 organized session, 1 presentation);
– ISB3D; Valenciennes, June (1 presentation);
– MCBMS'06 "Modelling and Control in Biomedical Systems"; Reims, September (1 presentation);
– 5th School on "Topics in Nonlinear Dynamics"; Naples, September (2 presentations);
– IROS; Beijing, October (2 presentations);
– HUMANOIDS; Genova, December (1 presentation);
– Various Siconos meetings.

10. Bibliography

Major publications by the team in recent years

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