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Project-Team BIPOP

Nonsmooth Dynamics and Optimization

Grenoble - Rhône-Alpes

Theme : Modeling, Optimization, and Control of Dynamic Systems

Activity
Report

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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[1], etc;
- numerical methods for nonsmooth optimization, and more generally the connection between continuous and combinatorial optimization.

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[1] metal-oxyde semiconductor

3. Scientific Foundations

3.1. Dynamic non-regular systems

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

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

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: $0\le y\perp\lambda\ge 0$ 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 $\langle\dot{x}(t)+F(x(t),t),v-x(t)\rangle\ge 0$ 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 [5], 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

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 [10]) 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 [12], [11].
- 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 [13].

4. Application Domains

4.1. Introduction

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[2], 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.

4.2. Computational neuroscience

Modeling in neuroscience makes extensive use of nonlinear dynamical systems with a huge number of interconnected elements. Our current theoretical understanding of the properties of neural systems is mainly based on numerical simulations, from single cell models to neural networks. To handle correctly the discontinuous nature of integrate-and-fire networks, specific numerical schemes have to be developed. Our current works focus on event-driven, time-stepping and voltage-stepping strategies, to simulate accurately and efficiently neuronal networks. Our activity also includes a mathematical analysis of the dynamical properties of neural systems. One of our aims is to understand neural computation and to develop it as a new type of information science.

4.3. Electronic circuits

Whether they are integrated on a single substrate or as a set of components on a board, electronic circuits 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.

4.4. Walking robots

As compared to rolling robots, the walking ones – for example hexapods – possess definite advantages 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.

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[2] model predictive control

4.5. Optimization

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.

4.6. Computer graphics Animation

A new application in Bipop is the simulation of complex scenes involving many interacting objects. Whereas the problem of collision detection has become a mature field those recent years, simulating the collision response (in particular frictious contacts) in a realistic, robust and efficient way, still remains an important challenge. Another related issue we began to study is the simulation of heterogeneous objects such as granular or fibrous materials, which requires the design of new high-scales models for dynamics and contacts; indeed, for such large systems, simulating each interacting particle/fiber individually would be too much time-consuming for typical graphics applications. Finally, our current activity includes the shape control of simulated objects, which is of great importance in the field of artistic design, for the making of movies and video games for example. Such problems typically involve constrained optimization.

5. Software

5.1. Nonsmooth dynamics: Siconos

Participant: Vincent Acary.

In the framework of the European project Siconos, Bipop was 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

Participant: Pierre-Brice Wieber.

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

Participant: Claude Lemaréchal.

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. They are generally available at http://www-rocq.inria.fr/~gilbert/modulopt/; M1QN3 is also distributed under GPL.

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 [4] 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 [10], Chap. 9 of [4]).

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.

5.4. Simulation of fibrous materials

Participants: Florence Bertails-Descoubes, Gilles Daviet, Florent Cadoux.

The goal of the MECHE ADT, started in September 2009 and planned for 2 years, is to develop a software for simulating the dynamics of assemblies of thin rods (such as hair), subject to contact and friction. This software combines a panel of well-accepted models for rods (ranging from reduced coordinates to maximal coordinates models, and including models recently developed by some members of the group) with classical as well as innovative schemes for solving the problem of frictious contact (incorporating the most recent results of the group). The aim of this software is twofold: first, we would like to compare and analyse the performance of nonsmooth schemes for the frictious contact problem, in terms of realism (capture of dry friction, typically), robustness, and computational efficiency. This study will be conducted onto the different rod models that are available in the software. Second, such a software will help us understand the behaviour of a fibrous material (such as hair) through virtual experiments, thanks to which we hope to identify and understand some important emergent phenomena. In the past, such fibrous materials have been seldom studied (though many applications have come out those years - e.g. cosmetology and computer graphics), and we believe that numerical simulation will give to us some important hints on how to model such a system macroscopically.

An associate engineer, Gilles Daviet, have been hired in September 2009 to work full-time on the MECHE project.

6. New Results

6.1. Modeling

6.1.1. Simulation of electrical circuits as nonsmooth dynamical systems

Participants: Vincent Acary, Olivier Bonnefon, Bernard Brogliato.

DC-DC converters are usually difficult to simulate with classical tools like SPICE because of the highly nonlinear behaviour of some components and the frequent occurrence of intrinsically generated switching events.

The simulation of such circuits modelled as nonsmooth systems has been successfully achieved with a clear advantage over several SPICE simulators and a simulator belonging to the hybrid modelling approach [16], [33]. Let us also mention the results in [38] that concern the existence/uniqueness of solutions to variational inequalities, with an application to some classes of circuits.

6.1.2. Simulation of spiking neuronal networks

Participant: Arnaud Tonnelier.

The numerical simulation of neural networks requires special attention to reproduce accurately the firing times of spiking neurons, while allowing efficient simulation of large networks. Event-driven strategies have become increasingly popular since they allow the simulation of spiking neural networks exactly, with a computational cost similar to classical time-stepping schemes. Previous works were limited to linear integrate-and-fire neurons. In [52] we extend event-driven schemes to a class of nonlinear integrate-and-fire models. Results are presented for the quadratic integrate-and-fire model with exponential synaptic currents.

The development of an event-driven simulation algorithm has to be done case by case. In [14] we propose a generic technique, *voltage-stepping schemes*, that is based on a discretization of the voltage state-space of individual neurons. The new simulation strategy defines a local event-driven method inducing an implicit activity-dependent time stepping scheme. Long time-steps are used when the neuron is slowly varying, whereas small time-steps are used in periods of intense activity. Our method is illustrated on nonlinear integrate-and-fire models. The efficiency of voltage-stepping schemes for the numerical simulation of spiking neural networks has been assessed in [47]. We recasted voltage-stepping in a general framework, the discrete event system specification (DEVS) and we implemented the method in MVASpike, a generic event-driven simulator for spiking neurons. The efficiency of the method is assessed through simulations and comparisons with a modified time-stepping scheme of Runge-Kutta type. We demonstrated numerically that the original order of voltage-stepping is preserved when simulating connected spiking neurons, independently of the network activity and connectivity.

6.1.3. Neural dynamics

Participants: Arnaud Tonnelier, David Salinas.

The quadratic integrate-and-fire model (QIF) with adaptation is commonly used as an elementary neuronal model that reproduces the main characteristics of real neurons. In [15], we introduce a QIF neuron with a nonlinear adaptive current. This model reproduces the neuron-computational features of real neurons and is analytically tractable. It is shown that, under a constant current input, chaotic firing is possible. In contrast to previous studies, the neuron is not sinusoidally forced. We show that the spike-triggered adaptation is a key parameter to understand how chaos is generated.

Precise spatiotemporal sequences of spikes are observed in many neural systems and are thought to be involved in the neural processing of sensory stimuli. In [28] we examine the capability of spiking neural networks to propagate stably spatiotemporal sequences of spikes. We derive some analytical results for the wave speed and show that the stability of simple waves is determined by the Schur criteria. The transmission of a sequence of several spikes is related to the existence of stable composite waves, i.e. the existence of stable spatiotemporal periodic traveling waves. We show that the stability of composite waves is related to the roots of a system of multivariate polynomials. A fundamental aspect that controls the dynamics of traveling waves in networks is the underlying discrete structure of the space. Discreteness has a strong effect on propagating activity patterns and, for instance, anisotropy or propagation failure can be observed. Numerical simulations and analytical calculations have been carried out to characterize more precisely these properties [41].

6.1.4. Inverse modeling of mechanical rods

Participants: Florence Bertails, Alexandre Derouet-Jourdan.

High-order models for rods such as the super-helix model [3] are able to finely capture the bending and twisting deformations of thin elastic strands, given a set of input parameters. Controlling their input shape would be desirable in many design applications (such as hairstyling, reverse engineering, etc.), but solving the corresponding inverse problem is not straightforward. In our recent work [21], we introduce a new method for automatically converting a smooth sketched curve into a 2d dynamic curve at stable equilibrium under gravity. Our approach proceeds in two steps. We first present a new technique to fit a smooth piecewise circular arcs curve to a sketched curve. Then we show how to compute the physical parameters of a 2d super-helix (super-circle) so that its stable rest shape under gravity exactly matches the fitted circular arcs curve. We demonstrate the interactivity and controllability of our approach on various examples where a user can intuitively setup efficient and precise 2d animations by specifying the input geometry. We are currently extending this approach to the three-dimensional problem, as well as to the handling of contacts at equilibrium nonsmooth problem.

6.1.5. Multiple impacts modelling

Participants: Bernard Brogliato, Hongjian Zhang, Ngoc-Son Nguyen.

The work consists of studying two systems: the rocking block and tapered chains of balls, using the Darboux-Keller model of multiple impacts previously developed. The objectives are threefold: 1) show that the model predicts well the motion by careful comparisons with experimental data found in the literature, 2) study the system's dynamics and extract critical kinetic angles that allow the engineer to predict the system's gross motion, 3) develop numerical code inside the SICONOS platform that incorporates the model of multiple impact. We are currently developping a common work with CEMAGREF Grenoble on the modeling of falling rocks, in which this model could be quite useful.

6.1.6. Simulating contact with Coulomb friction in fiber assemblies

Participants: Florence Bertails-Descoubes, Vincent Acary, Gilles Daviet.

In the case of hair dynamics, we have shown in [42] that optimization-based methods such as the approach by Alart and Curnier [44], little known in the computer graphics literature, outperform classical schemes of computer graphics (typically, penalty-based approaches) for solving the frictious contact problem, both in terms of realism and robustness.

6.2. Optimization

6.2.1. Nonsmooth analysis of spectral sets

Participant: Jérôme Malick.

Spectral sets are sets of matrices that depend only on the constraints on the eigenvalues: S is a spectral set if $S = \lambda^{-1}(C)$ with C a subset of $\mathbb{R}^n$. A spectral set S inherits from properties of the underlying set C, such as convexity. We prove in [45] that the spectral sets associated to smooth manifolds in $\mathbb{R}^n$ (having some local symmetry) are themselves manifolds in the space of matrices. This result looks simple but generalizes several useful particular cases, and was extremely difficult to prove: we brace together tools from nonsmooth analysis, differential geometry, group theory and spectral analysis.

6.2.2. Semidefinite programming and applications

Participant: Jérôme Malick.

Many problems in Control and Combinatorial Optimization have modelizations as semidefinite optimization problems; but as for numerical resolution, this approach is limited by the performances of semidefinite optimization solvers that often run into numerical trouble when the sizes of problems get large. We contribute in solving partly this for 2 particular cases :

- We have worked with Frederic Roupin (Prof. at Paris XIII) on the use of semidefinite programming to solve combinatorial optimization problems. Within exact resolution schemes (like branch-and-bound), the main point is to have bounds with a good balance between tightness and computing times. We first proposed a new family of semidefinite bounds for 0-1 quadratic problems with linear or quadratic constraints [25], [39]. An interesting feature is that he final accuracy level is controlled by real parameter acting like a cursor. This gives ways to trade computing time for a (small) deterioration of the quality of the usual semidefinite bounds, in view of enhancing this efficiency in exact resolution schemes. Extensive numerical comparisons et tests showed the superior quality of our bounds on standard test-problems (unconstrained 0-1 quadratic problems, heaviest k-subgraph problems, and graph bisection problems). We also embedded our bounds within a simple branch-and-bound algorithm to solve heaviest k-subgraph problems to optimalit [40]. This algorithm takes advantage of the new bounds to prune very well in the search tree. Its performances are then comparable with the best method (based on convex quadratic relaxation using CPLEX as an engine). In practice, our method works particularly fine on the most difficult instances (with a large number of vertices, small density and small k).

- We propose in [9] a new approach by projection to solve semidefinite feasibility problems - as for exemple computing SOS decomposition of Lyapunov polynoms. This natural, geometric idea is as simple as efficient : we release a short Matlab software implementing this idea, and as shown in [9], it is competitive for solving those semidefinite feasibility problems with more evoluated reliable tools (as SeDuMi).

- We wrote a chapter [34] of the handbook on semidefinite programming (to be published by Kluwer): we review all the numerical methods to solve special types of semidefinite optimization problems (semidefinite projections) and their use for developing new algorithms for a bunch of semidefinite optimization methods (classical linear semidefinite problems and rank-constraint semidefinite problems). We insist on semidefinite relaxations of combinatorial problems (such as Lovasz' number) and of nonconvex problems (such as polynomial optimization problems).

6.2.3. Marginal prices in electricity production

Participants: Jérôme Malick, Claude Lemarechal.

Formulating the daily production problem as $\min c(p)$ (production cost) subject to $A = d$ (balance constraint), EdF rather solves $\min c(p) + v(Ap - d)$. One reason is that satisfying the balance constraint exactly is impossible and the penalty function v helps assessing schedules that do not meet the demand. Now, beyond computing schedules, marginal prices of the demand are needed. Classically, they are given by the dual solution but penalizing the constraints introduces a bias. In [35], we study the impact of this penalty technique. Among other things, this study confirms the importance of the so-called pseudo-schedule (i.e. the solution of the convexified problem).

6.2.4. Proximal algorithm for smooth functions

Participants: Marc Fuentes, Claude Lemaréchal, Jérôme Malick.

This research was motivated by the minimization of a smooth but ill-conditioned function f, such as presented in [49]. For this, the proximal approach consists in constructing the sequence $x_{k+1} = p(x_k)$, where $p(x)$ minimizes the function $p \mapsto f(p) + \frac{1}{2}|p - x|^2$. Unless f is simple enough, actual implementations require a stopping rule for the internal minimization algorithm computing $p(x_k)$. The rationale for most such rules is to guarantee $|x_{k+1} - p(x_k)| \leqslant \varepsilon_k$, where ε_k is essentially pre-assigned. We propose in [46] a rule based on a sufficient decrease $f(x_k) - f(x_{k+1})$, applicable when f is differentiable. We prove convergence of the resulting algorithm and illustrate it on some test-problems from the CUTEr library.

6.3. Control

6.3.1. Observer design

Participants: Bernard Brogliato, Christophe Prieur.

The general problem of state observation for nonsmooth dynamical systems, or hybrid dynamical systems, remains largely open, in particular for systems whose trajectories may jump. In [22] solutions are proposed for the design of asymptotic observers for various classes of nonsmooth systems (differential inclusions, complementarity systems). The problem of "closing the loop" (the separation principle) is also solved in particular cases. We are currently extending these results to the cases of a local bounded variation input, and systems with normal cones to prox-regular sets. Prox-regular sets are a natural extension of convex sets where a parameter "measures" the non-convexity, and are therefore a very nice framework for relaxing convexity as in our previous works. Let us also mention [19] that concerns the existence and uniqueness of solutions of set-valued Lur'e systems, with an aplication to observer design.

6.3.2. Trajectory tracking

Participants: Bernard Brogliato, Van Hoa Nguyen.

In these works [26], [27] the problem of extending the so-called passivity-based controllers to Lagrangian systems with unilateral constraints is considered. The first work [26] treats fully actuated rigid systems. The second work [27] deals with the case when joint flexibilities are present. This is thought to be quite important since impacts are likely to excite vibrational modes and possibly destabilize the closed-loop system. We first derive a suitable stability criterion, then we design a switching control algorithm and numerical simulations are performed with the Moreau's time-stepping scheme of the SICONOS platform.

6.3.3. Digital sliding mode control

Participants: Vincent Acary, Bernard Brogliato.

The problem of digital sliding mode controllers is a long-standing issue not yet satisfactorily solved. We propose in [17] ideas which are inspired from the numerical methods of contact mechanics [1] and which permit a) to suppress the numerical chattering, b) to obtain a smooth stabilization on the sliding surfaces. The work is continued together with Yury Orlov in more general cases where the system is acted upon by disturbances and a disturbance estimation is added [37].

6.3.4. Discrete-time discontinuous systems

Participants: Vincent Acary, Bernard Brogliato, Carmina Georgescu, Scott Greenhalg, Thorsten Schindler.

We focus on some classes of discontinuous dynamical systems like relay systems, linear complementarity systems. The objectives are to show that the time-stepping numerical schemes like Moreau's algorithm can be used to successfully simulate such systems (like in the case of biological systems like gene networks), and also to study the properties of these schemes for finite nonzero time steps (like preservation of disssipativity properties). A preliminary work on the design of higher-order time-stepping schemes (which usually are or order one or less) is presented in [36]. Further work deals with timestepping schemes for nonsmooth dynamical systems. So far, these schemes are locally of order one both in smooth and nonsmooth segments. This is inefficient for applications with few events like circuit breakers. To consistently improve the behavior during smooth episodes, the traditional schemes are being embedded in time discontinuous Galerkin methods. After establishing the correct mathematical setting, a Petrov-Galerkin distributional differential inclusion is outlined. The bouncing ball example illustrates its capabilities.

6.4. Locomotion analysis

6.4.1. Synchronous imitation of human motion by a humanoid robot

Participants: Mehdi Benallegue, Pierre-Brice Wieber.

Interactions between humans and robots require that each one is able to understand and interpret the other's actions. From the point of view of the robot, this means: (i) to move in a way that can be naturally interpreted by humans and (ii) to be able to understand the humans' actions. Studies in Neuroscience in the case of interactions between humans indicate that these two abilities might be tightly linked in the human's brain: "we understand actions when we map (...) the observed action onto our motor representation of the same action" [50]. In this work, we consider that the "motor representation" of a task is the control law, and "mapping an observed action" means finding the corresponding control parameter, in an observer-based approach. Our current simulations involve a robot imitating another robot realizing some random walk steps, using simulated inertial sensors as measurements of the demonstrator's motions. Our initial results show that the imitating robot is able to detect step position on time even if the two control laws involved in the two robots don't match exactly. And in the case the two robots use exactly the same controller, the imitator is even able to guess very precisely what the next step is going to be thanks to preparatory motions. We are currently working on imitation from human motion measurements.

6.4.2. Hierarchic QP solver

Participant: Pierre-Brice Wieber.

In collaboration with the LAAS-CNRS and the CEA-LIST, we have worked on a new solver for Hierarchized Inverse Kinematics of a robot. We have shown in 2009 that this problem can be seen as a sequence of Quadratic Programs which have to be solved at each sampling time [48]. This observation allows introducing inequality constraints seamlessly in a framework that has been limited for two decades to only equality constraints. This year, we have observed that this sequence of QPs can be seen as solving a unique multi-objective Quadratic Program, with a Lexicographic ordering of the different cost functions. Building on this observation, we have proposed to replace the sequence of QPs by a unique active set method that can deal directly with these lexicographically ordered multiple objectives [31]. This improves the computation time by an order of magnitude and allows online computations at 10kHz, what is necessary for the control of complex unstable robots such as humanoid robots, our target application.

6.4.3. Modeling of human balance in public transports

Participants: Pierre-Brice Wieber, Zohaib Aftab.

In a new collaboration with the INRETS, we begin working on modeling human balance in public transports. The first step has been to aggregate biomechanical studies and numerical models proposed in robotics, and compare how they match or mismatch in situations of strong perturbations that require that a step be made in order to recover balance. We began developing a Model Predictive Control based approach for both situations when a step is required or not, and we began fitting its parameters to recover the behavior that can be observed in biomechanical studies [29].

6.4.4. Model Predictive Control for Biped Walking

Participants: Pierre-Brice Wieber, Andrei Herdt.

We have refined our Model Predictive Control scheme for biped walking in order to allow guiding the walking motion through a desired motion of the head or hand of the robot. The whole motion of the robot, placement and orientation of the feet and balancing of the Center of Mass, is free and guided solely by the desired motion of the head or hand. This allows in some sense "walking without thinking about it". We were able then to connect this online motion generation scheme with the vision system of the robot, enabling a direct feedback of the vision sensors on the locomotion of the robot. This allows a more precise positioning of the robot with respect to its environment. This algorithm has been validated on the humanoid robot HRP-2 [23], [32], [30].

6.5. Software development

6.5.1. MECHE toolbox

Participants: Florence Bertails, Gilles Daviet.

The main functionalities developed in 2010 for the MECHE software are:

- The development of one supplementary rod model, namely the Discrete Elastic Rod model [2].
- The development of a bunch of new frictional contact solvers including:
  - The new solver proposed in Cadoux's PhD's thesis [43], in its primal and dual versions.
  - A one-contact analytical solver that simply eliminates take-off and stick cases and solves for the sliding problem, exactly formulated as a root-finding problem of a polynom of order four (collaboration with O. Bonnefon).
  - A Newton method based on the Fischer-Burmeister function [51], adapted to the frictional case.
  - A Gauss-Seidel algorithm incorporating any one-contact solver.
- The development of a bilateral constraint solver.
- The development of a collision detection scheme between rods (bounding cylinders) and arbitrary meshes.
- The optimization of the solvers through code parallelization (on the CPU) and optimization.

6.5.2. Platform development: Siconos

Participants: Vincent Acary, Olivier Bonnefon.

The main achievements for the Siconos platform are

- *Siconos/Kernel*. Improvements and enhancements of
  - Modeling part: new NewtonEuler Dynamical systems;
  - Example library: example library with Optimal control example and Relay Systems
- Improvements and extensions of the documentation.

7. Contracts and Grants with Industry

7.1. Industrial contracts

ANR Cheveux: Modeling and dynamic simulation of hair in the context of feature films production. Partners: Neomis Animation SARL, BeeLight SARL, Institut Jean Le Rond d'Alembert (UPMC-CNRS), Inria (Bipop, Evasion and Artis).

ANR Saladyn: Numerical tools for simulating dynamics systems in mechanics; Partners: INRIA Bipop, LMGC Montpellier, EdF, Schneider Electric.

FUI Romeo: Partners: Aldebaran Robotics, Acapela, As An Angel, INRIA, Institut de la Vision, LAAS, LIMSI, LIST, LISV, LPPA, Spirops, Telecom Paris Tech, Voxler (http://www.projetromeo.com/index_en.html).

EdF: Documentation of the `noisedf` software

L'OREAL: "contrat d'étude" with L'Oréal performed in January 2010, for adding extended functionalities to the hair simulation software transfered in 2006 (F. Bertails-Descoubes)

7.2. Other grants

–ANR Saladyn, programme COSINUS.
–ANR Multiple Impact, programme BLANC.
–FUI Romeo.
–ANR Cheveux.

–ANR R-Blink, programme Jeunes Chercheurs.
–MSTIC Projet "math-IT" funded by Grenoble University.
– ASSOCIATE TEAM: SHARE, Simulation of virtual Humans and Animals interacting with Realistic Environments, with theuniversity of Vancouver.

8. Dissemination

8.1. Software

– M2FC1 (a code for nonsmooth-nonconvex optimization) sent to Mentor Graphics (design of robust analog circuits).

8.2. Animation of the scientific community

B. Brogliato is:
– Member of the International Program Committees of 7th International Multi-Conference on Systems, Signals and Devices SSD'10, June 27-30 2010, Amman, Jordan; 7th International Conference on Informatics in Control, Automation and Robotics ICINCO 2010, 15-18 June, Funchal, Madeira, Portugal; Conférence Internationale Francophone d'Automatique, CIFA 2010, 2-4 juin 2010, Nancy.
– Guest Editor (with P. Piiroinen, L. Lopez and T. Kuepper) of the special issue "Discontinuous Dynamical Systems: Theory and Numerical Methods" of Mathematics and Computer in Simulation (scheduled for 2011).

F. Bertails has been a reviewer for
– ACM SIGGRAPH since 2007
– Eurographics since 2005
– ACM Solid and Physical Modeling Symposium since 2008.

She has been a member of the national SPECIF PhD award boarding since 2007.
– J. Malick is member of the GTAI-COST (INRIA grant selection committee).
– J. Malick co-organized workshop on optimization and applications (CAOA2010, January 2010) in the occasion of the 65th birthday of Claude Lemarechal.

8.3. Teaching

– ENSIMAG: J. Malick, F. Bertails-Descoubes: "Numerical Optimization", 60h and 22.5h respectively.
– Université de Limoges, laboratoire XLIM: B. Brogliato (master 2 recherche Math. Appl., 13.5h)
– ENSIMAG: J. Malick, "Optimization methods in finance", ENSIMAG 3A, 20h (janv-mars 2010)

8.4. Participation to conferences, seminars

J. Malick gave a talk at:
– - ROADEF2010, Toulouse, February 2011
– - European Workshop on Mixed Integer Nonlinear Programming, Luminy, April 2010

B. Brogliato gave a talk at
– -AIMS 8th AIMS conference Conference on Dynamical Systems, Differential Equations and Applications, Dresden University of Technology, Dresden, Germany, May 25-28.
– -Seminar at Université de Montpellier (April 2010), Department of Mathematics.
– -Seminar at Université de Saint-Etienne (December 2010), Department of Mathematics.
– -IUTAM Symposium on Nonlinear Dynamics for Advanced Technologies and Engineering Design, university of Aberdeen, Scotland, 27-30 July 2010.

P.B. Wieber gave talks at:
– -IROS 2010 (IEEE International Conference on Intelligent Robots and Systems).
– -ICRA 2010 (EEE Int. Conf. on Robotics and Automation).

– - Humanoids 2010 (IEEE International Conference on Humanoid Robotics).
– -JNRH 2010 (Journees Nationales de Robotique Humanoide).

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