Activity Report 2013

Project-Team COPRIN

Constraints solving, optimization and robust interval analysis

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Robotics

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Project-Team COPRIN

Keywords: Interval Analysis, Numerical Methods, Robotics, Human Assistance

Creation of the Project-Team: 2002 February 01, end of the Project-Team: 2013 December 31.

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2. Overall Objectives

2.1. Overall Objectives

The COPRIN project-team scientific objective is to develop and implement systems solving algorithms based on constraints propagation methods, interval analysis and symbolic computation, with interval arithmetic as the primary tool. The academic goals of these algorithms is to provide *certified solutions* to generic problems (e.g. to calculate all solutions of a system of equations within a search space) or to manage the *uncertainties* of the problems (e.g. to provide an enclosure of all solutions of a system of equations whose coefficients are intervals). These academic goals may also be declined in applicative goals. For example we may determine a domain that describes all possible dimensions of a mechanism that has to satisfy a set of performance requirements. Given this domain it will be possible to determine nominal dimensions for the mechanism so that even if there are bounded variations between the real dimensions and the nominal ones, then the real mechanism will still satisfy the requirements: hence we will be able to manage manufacturing uncertainties for the real process.

Our research aims to develop algorithms that can be used for any problem or are specific to a given class of problems, especially problems that are issued from application domains for which we have an internal expertise (such as mechanism theory and robotics).

A key point of these algorithms is that they rely heavily on symbolic pre-processing and formal calculation in order to improve the efficiency of the problem at hand. Our long term goal is to be able to synthesize automatically a specific solver according to the structure of the problem that has to be managed.

Implementation of the algorithms will be performed within the framework of general purpose software such as `Scilab`, `Maple`, `Mathematica` and will be based on the already existing library `ALIAS`, that are still being developed mostly for internal use.

Since a theoretical complexity analysis of interval analysis based solving algorithms is usually extremely difficult, the efficiency of the algorithm is systematically experimentally evaluated through `ALIAS` on various realistic test examples.

Dissemination is also an essential component of our activity because interval analysis based methods are not sufficiently known in the engineering and academic communities.

The study of robotics problems is a major focus point of the COPRIN project. In this field our objectives are:

- to develop methods for the analysis of existing robots, taking into account uncertainties in their modeling that are inherent to such mechatronic devices
- to propose innovative robotic systems
- to develop a design methodology for complex robotic systems that guarantees a required level of performance for the **real** robot. Our methodology aims at providing not a single design solution but a set of solutions offering various compromises among the performances. Furthermore the solutions will be robust with respect to errors in the realization of the real robot (e.g. due to manufacturing tolerances and control errors)

Experimental work and the development of our own prototypes are strategic for the project as they allow us to validate our theoretical work and to discover new problems that will feed in the long term the theoretical analysis developed by the team members.

We have started since five years a strategic move toward **assistance robots** (see section 6.1.2). Our long term goal will be to provide robotized devices for assistance, including smart objects, that may help disabled, elderly and handicapped people in their personal life. Our goals for these devices are that

- they can be adapted to the end-user and to its everyday environment
- they should be affordable and minimally intrusive
- they may be controlled through a large variety of simple interfaces
- they may eventually be used to monitor the health status of the end-user in order to detect emerging pathology

As this topic is very large and cannot be managed by a single project-team COPRIN has been one of the main proponent for the creation of the "Action d'Envergure National" PAL (Personnal Assistant Living), that has been accepted in 2011 and that is coordinated by D. Daney.

In summary COPRIN has two major research axes, interval analysis and robotics. The coherence of these axis is that interval analysis is a major tool to manage the uncertainties that are inherent to a robotized device, while robotics provides realistic problems which allow us to develop, test and improve interval analysis algorithms.

COPRIN was created in 2002 and therefore has reached the twelve years limit. It will be followed by a new project-team called HEPHAISTOS, that will be focused on assistance robotics.

3. Research Program

3.1. Interval analysis

We are interested in real-valued system solving ($f(X) = 0$, $f(X) \leq 0$), in optimization problems, and in the proof of the existence of properties (for example, it exists X such that $f(X) = 0$ or it exist two values X_1, X_2 such that $f(X_1) > 0$ and $f(X_2) < 0$). There are few restrictions on the function f as we are able to manage explicit functions using classical mathematical operators (e.g. $\sin(x + y) + \log(\cos(e^x) + y^2)$ as well as implicit functions (e.g. determining if there are parameter values of a parametrized matrix such that the determinant of the matrix is negative, without calculating the analytical form of the determinant).

Solutions are searched within a finite domain (called a *box*) which may be either continuous or mixed (i.e. for which some variables must belong to a continuous range while other variables may only have values within a discrete set). An important point is that we aim at finding all the solutions within the domain whenever the computer arithmetic will allow it: in other words we are looking for *certified* solutions. For example, for 0-dimensional system solving, we will provide a box that contains one, and only one, solution together with a numerical approximation of this solution. This solution may further be refined at will using multi-precision.

The core of our methods is the use of *interval analysis* that allows one to manipulate mathematical expressions whose unknowns have interval values. A basic component of interval analysis is the *interval evaluation* of an expression. Given an analytical expression F in the unknowns $\{x_1, x_2, ..., x_n\}$ and ranges $\{X_1, X_2, ..., X_n\}$ for these unknowns we are able to compute a range $[A, B]$, called the interval evaluation, such that

$$\forall \{x_1, x_2, ..., x_n\} \in \{X_1, X_2, ..., X_n\}, A \leq F(x_1, x_2, ..., x_n) \leq B \quad (1)$$

In other words the interval evaluation provides a lower bound of the minimum of F and an upper bound of its maximum over the box.

For example if $F = x\ sin(x + x^2)$ and $x \in [0.5, 1.6]$, then $F([0.5, 1.6]) = [-1.362037441, 1.6]$, meaning that for any x in [0.5,0.6] we guarantee that $-1.362037441 \leq f(x) \leq 1.6$.

The interval evaluation of an expression has interesting properties:

- it can be implemented in such a way that the results are guaranteed with respect to round-off errors i.e. property 1 is still valid in spite of numerical errors induced by the use of floating point numbers
- if $A > 0$ or $B < 0$, then no values of the unknowns in their respective ranges can cancel F
- if $A > 0$ ($B < 0$), then F is positive (negative) for any value of the unknowns in their respective ranges

A major drawback of the interval evaluation is that $A(B)$ may be overestimated i.e. values of $x_1, x_2, ..., x_n$ such that $F(x_1, x_2, ..., x_n) = A(B)$ may not exist. This overestimation occurs because in our calculation each occurrence of a variable is considered as an independent variable. Hence if a variable has multiple occurrences, then an overestimation may occur. Such phenomena can be observed in the previous example where $B = 1.6$ while the real maximum of F is approximately 0.9144. The value of B is obtained because we are using in our calculation the formula $F = xsin(y + z^2)$ with y, z having the same interval value than x.

Fortunately there are methods that allow one to reduce the overestimation and the overestimation amount decreases with the width of the ranges. The latter remark leads to the use of a branch-and-bound strategy in which for a given box a variable range will be bisected, thereby creating two new boxes that are stored in a list and processed later on. The algorithm is complete if all boxes in the list have been processed, or if during the process a box generates an answer to the problem at hand (e.g. if we want to prove that $F(X) < 0$, then the algorithm stops as soon as $F(\mathcal{B}) \geq 0$ for a certain box $\mathcal{B}$).

A generic interval analysis algorithm involves the following steps on the current box [1], [8], [5]:

1. *exclusion operators*: these operators determine that there is no solution to the problem within a given box. An important issue here is the extensive and smart use of the monotonicity of the functions
2. *filters*: these operators may reduce the size of the box i.e. decrease the width of the allowed ranges for the variables [14]
3. *existence operators*: they allow one to determine the existence of a unique solution within a given box and are usually associated with a numerical scheme that allows for the computation of this solution in a safe way
4. *bisection*: choose one of the variable and bisect its range for creating two new boxes
5. *storage*: store the new boxes in the list

The scope of the COPRIN project is to address all these steps in order to find the most efficient procedures. Our efforts focus on mathematical developments (adapting classical theorems to interval analysis, proving interval analysis theorems), the use of symbolic computation and formal proofs (a symbolic pre-processing allows one to automatically adapt the solver to the structure of the problem), software implementation and experimental tests (for validation purposes).

3.2. Robotics

COPRIN has a long-standing tradition of robotics studies, especially for closed-loop robots [4]. We address theoretical issues with the purpose of obtaining analytical and theoretical solutions, but in many cases only numerical solutions can be obtained due to the complexity of the problem. This approach has motivated the use of interval analysis for two reasons:

1. the versatility of interval analysis allows us to address issues (e.g. singularity analysis) that cannot be tackled by any other method due to the size of the problem
2. uncertainties (which are inherent to a robotic device) have to be taken into account so that the *real* robot is guaranteed to have the same properties as the *theoretical* one, even in the worst case. This is a crucial issue for many applications in robotics (e.g. medical or assistance robot)

Our field of study in robotics focuses on *kinematic* issues such as workspace and singularity analysis, positioning accuracy, trajectory planning, reliability, calibration [12], [11], [10], [17], modularity management and, prominently, *appropriate design*, i.e. determining the dimensioning of a robot mechanical architecture that guarantees that the real robot satisfies a given set of requirements. The methods that we develop can be used for other robotic problems, see for example the management of uncertainties in aircraft design [6].

Our theoretical work must be validated through experiments that are essential for the sake of credibility. A contrario, experiments will feed theoretical work. Hence COPRIN works with partners on the development of real robots but also develops its own prototypes. We usually develop a new robot prototype every 6 years but since 2008 we have started the development of seven new robot prototypes, mostly related to assistance robotics. Furthermore we have extended our development to devices that are not strictly robots but are part of an overall environment for assistance. We benefit here from the development of new miniature, low energy computers with an interface for analog and logical sensors such as the Arduino or the Phidgets. We intend to make a full use of such devices, especially for assistance purpose

In term of applications we have focused up to now on the development of special machines (machine-tool, ultra-high accuracy positioning device, spatial telescope). Although this activity will be pursued, we have started in 2008 a long-term move toward *service robotics*, i.e. robots that are closer to human activity. In service robotics we are interested in domotics, smart objects, rehabilitation and medical robots and entertainment, that can be regrouped under the name of *assistance robotics* (see section 6.1.2). Compared to special machines for which pricing is not an issue (up to a certain point), cost is an important element for assistance robotics. While we plan to develop simple robotic systems using only standard hardware, our work will focus on a different issue: *adaptability*. We aim at providing assistance devices that are adapted to the end-user, its trajectory of life and its environment, are easy to install (because installation uncertainties are taken into account at the design stage), have a low intrusivity and are guaranteed to fulfill a set of requirements.

4. Application Domains

4.1. Application Domains

While the methods developed in the project can be used for a very broad set of application domains (for example we have an activity in CO2 emission allowances [18]), it is clear that the size of the project does not allow us to address all of them. Hence we have decided to focus our applicative activities on *mechanism theory*, where we focus on *optimal design* and geometrical modeling of mechanisms. Along the same line our focus is *robotics* and especially *service robotics* which includes rescue robotics, rehabilitation and assistive robots for elderly and handicapped people (section 6.1.2). Although these topics were new for us in 2008 we have spent two years determining priorities and guidelines by conducting about 200 interviews with field experts (end-users, praticians, family and caregivers, institutes), establishing strong collaboration with them (e.g. with the CHU of Nice-Cimiez) and putting together an appropriate experimental setup for testing our solutions. A direct consequence of setting up this research framework is a reduction in our publication and contract activities. But this may be considered as an investment as assistance robotics will constitute the major research axis of the project on the long term.

5. Software and Platforms

5.1. Introduction

Software development is an essential part of the research done by COPRIN since a large part of our methods can only be validated experimentally (both for our numerical experiments and in robotics). Software developments follow various directions:

1. interval arithmetic: although we do not plan to work in this very specialized area (we generally rely on existing packages) interval arithmetic is an important part of our interval analysis algorithms and we may have to modify the existing packages so as to deal, in particular, with multi-precision and arithmetic extensions
2. interval analysis libraries: we daily use the ALIAS library that has been designed in the project and is still under development. A long term work is to develop a generic programming framework that allows for modularity and flexibility, with the objectives of testing new functionalities easily and building specific solvers by a simple juxtaposition of existing modules
3. interface to interval analysis: in our opinion interval analysis software must be available within general purpose scientific software (such as `Maple`, `Mathematica`, `Scilab`) and not only as a stand-alone tool. Indeed most end-users are reluctant to learn a new programming language just to solve problems that are only small elements of a more general problem. Furthermore interval analysis efficiency may benefit from the functionalities available in the general purpose scientific software.

5.2. Interval analysis libraries

5.2.1. ALIAS

Participants: David Daney, Jean-Pierre Merlet [correspondant], Odile Pourtallier.

The `ALIAS` library (*Algorithms Library of Interval Analysis for Systems*), whose development started in 1998, is a collection of procedures based on interval analysis for systems solving and optimization.

`ALIAS` is made of two parts:

- `ALIAS-C++`: the C++ library (87 000 code lines) which is the core of the algorithms
- `ALIAS-Maple`: the `Maple` interface for `ALIAS-C++` (55 000 code lines). This interface allows one to specify a solving problem within `Maple` and get the results within the same `Maple` session. The role of this interface is not only to generate the C++ code automatically, but also to perform an analysis of the problem in order to improve the efficiency of the solver. Furthermore, a distributed implementation of the algorithms is available directly within the interface.

Although these libraries are intended to be used within the project-team they can be freely downloaded as a library file (but the user may introduce its own code in several part of the package) and has been used for example at LIRMM and IRCCyN.

6. New Results

6.1. Robotics

6.1.1. Cable-driven parallel robots (CDPR)

6.1.1.1. Analysis of Cable-driven parallel robots

Participants: Laurent Blanchet, Jean-Pierre Merlet [correspondant], Yves Papegay, Rémy Ramadour.

We are still investigating the extremely complex analysis of the kinematics [24] of CDPRs assuming either rigid [21] [20], elastic or sagging cables.

We have also started an analysis of *cable configuration* of redundantly actuated CDPRs for control purposes. Indeed we have shown that for robot with rigid cables it is impossible to have, in a given pose, more than 6 cables in tension simultaneously: the set of cables under tension is called the cable configuration. However at a pose there may be different sextuplets of under tension cables that satisfy the kinematico-static equations. Each of these sextuplets exhibits different performances (e.g. maximal tension in the cables or sensitivity of the positioning to errors in the cable lengths). Hence it may be interesting for control purposes to select one of the sextuplet that is optimal with respect to a performance criteria and to enforce this configuration by letting *voluntary* the cables that are not in the sextuplet being slack (i.e. adjusting their lengths to be larger than the one required for the pose).

We have generalized this approach for a trajectory of a 4 cables CDPR with all cables attached to the same point of the platform. In that case only up to 3 cables may be under tension at the same time. We have designed an algorithm that determine the optimal cable configuration on the whole trajectory.

Simultaneously we have addressed part of an ambitious goal: a full simulation tool for CDPR. We assume a high level motion planning loop that calculate a motion order every Δt_1 second and send this command to an inner motor control loop that execute it by sending a command to the motor every Δt_2 second. Then we have a continuous time model of the motor that determine its velocity. The whole purpose is to calculate the pose of the platform together with the tensions in the cables. This simulation is extremely demanding and cannot be performed with classical software because of the changes in the cable configuration that have to be detected for determining the platform pose and cable tensions. We have succeeded for CDPR with rigid and elastic cables, furthermore introducing random errors in the cable length measurements. This tool has allowed us to show that cable tensions are very sensitive: for example a high level loop that is designed to minimize $\sum \tau_j^2$, where τ are the cable tensions, exhibits large difference with the objective as soon as discrete time-control is taken into account.

6.1.1.2. Certified Calibration of a Cable-Driven Robot Using Interval Contractor Programming

Participants: Julien Alexandre Dit Sandretto, David Daney, Gilles Trombettoni.

An interval based approach is proposed to rigorously identify the model parameters of a parallel cable-driven robot. The studied manipulator follows a parallel architecture having 8 cables to control the 6 DOFs of its mobile platform. This robot is complex to model, mainly due to the cable behavior. To simplify it, some hypotheses on cable properties (no mass and no elasticity) are done. An interval approach can take into account the maximal error between this model and the real one. This allows us to work with a simplified although guaranteed interval model. In addition, a specific interval operator makes it possible to manage outliers. A complete experiment validates our method for robot parameter certified identification and leads to interesting observations [9], [16], [15].

6.1.1.3. Tool for Agencement Analysis and Synthesis of CDPRs

Participants: Laurent Blanchet, Jean-Pierre Merlet [correspondant].

In the frame of FP7 project CABLEBOT, we are developing a methodology to analyze or synthesize a Cable Driven Parallel Robots configuration i.e. either to determine the performances of a given CDPR (e.g. maximal wire tensions over a given workspace) or, being given a list of requirements, to determine what what are **all** possible CDPR geometries that are guaranteed to satisfy the requirements. This tool relies heavily on our analysis of the CDPRs and on interval analysis.

To illustrate this approach we have developed a software that can be used to illustrate the workings/operating procedure of interval analysis through a 3D visualization. This software sets up a scenario of a CDPR in a warehouse and computes in real time its workspace under different constraints.

6.1.1.4. Visual-servoing of a parallel cable-driven robot

Participants: Rémy Ramadour, Jean-Pierre Merlet [correspondant], François Chaumette [correspondant].

`MARIONET-ASSIST` is a parallel cable-driven robot designed to move through large rooms in order to provide services such as walking-aid, lifting people or manipulating heavy loads. In order to experiment, a full-scaled flat with a crane robot has been built. Adding one or several low-cost cameras (the cost being here a fundamental constraint), visual-servoing control is used to provide a whole new set of useful services such as grasping objects in order to bring them to the end-user (if they are too heavy, too far, high or low), or cleaning the table after lunch. Using a parallel crane robot, we are able to cover a large workspace, the vision-control allowing us to obtain the precision required by the manipulation of daily-life objects. The collaborative implementation of the vision and the kinematic control of the robot gives us a way to make best use of the advantages of both parts, while overcoming their respective drawbacks.

This project is supported by the large-scale initiative PAL.

Experimentation showed that we are able to provide a much better accuracy and repeatability using visual-servoing. However, the velocity of the process is slowed because of several encountered problems :

- when there are changes in the distribution of tension between the wires, oscillations are occurring on the end-effector, affecting the movement of the camera in such a way that we can not rely on the measurements
- the methods used to first detect the object are not satisfactory. Also, the actual segmentation is not robust to luminance changes, the target may thus be lost during the process.

In order to overcome the first problem, we are working on an algorithm able to determinate the best sequence of configurations (distribution of tension) : we can avoid singularities and provide a more stable trajectory. The second problem has yet to be solved : we are at the moment looking into several methods, using for example k-nearest neighbors algorithms with different color spaces, gradient-based information and morphological preprocessing.

Finally, we experimented our device with others technologies developed within the context of PAL, in a full-scaled apartment located in Nancy (Loria-Inria).

6.1.2. Assistance robotics

This is now the core of our activity and our work on CDPR is deeply connected to this field as they are an efficient solution for mobility assistance, a high priority for the elderly, helpers and medical community. We have presented our vision of assistance robotics in several occasions [22], [23], [19].

6.1.2.1. Assessment of elderly frailty

Participants: Karim Bakal, Jean-Pierre Merlet.

The assessment of elderly frailty is a difficult concept because it involves the physical capacities of a person and its environment (health-care services, families, funds...). To evaluate the physical abilities, biomechanics tests can be underwent on the upper limb, lower limb or the whole body. In particularly, the motricity of the upper limb can be measured in terms of range of motion, velocity, acceleration or forces.

To analyze the velocity of the loads in the upper limb, a polytope interpretation is used. Currently the force polytope at the hand is calculated from the torques τ measured at each joint (shoulder, elbow and wrist) by a dynamometer (Biodex III, Biodex Medical Systems). But because of the redundancy of the upper limb (7 degrees of freedom), the dynamic equation ($\tau = \mathbf{J}^T F$) is difficult to solve. To find the minimal and maximal forces F that can be exerted at the hand from the measured torques, we may use the jacobian pseudo-inverse with the method of Chiacchio but this method is not well suited to manage the large uncertainties in the measurements. In the a reverse approach, the force at the hand will be measured by a 6-axis load sensor and the minimal and maximal joint torques will be computed by using interval analysis and compared with the measurements of the Biodex.

Moreover this analysis of the force capacities in the upper limb need to be connected to the daily activities or usual motion test monitored by the medical services. Therefore, a review of tests and questionnaires regularly used to measure the physical capacities has been performed. This review gather the type of mark, the exercises and the used sensors that can be employed in future experimentation. Also, this review will be discussed with medical staff to highlight relevant activities.

6.1.2.2. Walking analysis

Participants: Claire Dune, Ting Wang, Jean-Pierre Merlet [correspondant].

In the period 2009-2013 we have conducted in collaboration with Nice hospital a large experiment involving 54 subjects (30 elderly and 24 young adults) for determining walking pattern of elderly people using our instrumented walker `ANG-light`. We have started the processing of this large amount of data we some interesting results [25]:

- a classical walking test is the 10 meter walking test: the subject is asked to perform a 10m straight line trajectory and the result is the total time. Such test may have large consequences as it is used to determine the autonomy level and the resulting financial aid. Our test has surprisingly shown that when using a walker elderly people are usually faster that young adults
- on the other hand the maximal deviation with respect to the desired trajectory is much smaller for young adults than for elderly one. Furthermore few elderly have the same deviation and it may be considered as a signature of the walking pattern that is worth measuring

Our objective is now to analyze the maneuvers (half-turn and round-about) and to compare/complement the data with the one obtained with a Kinect. A long term objective is also to implement a model of a human walking with a walker and to use this model for an inverse calculation: measuring walking patterns indicators with the walker and calculating these indicators when not using the walker.

6.1.3. Experimental calibration of a high-accuracy space telescope

Participants: Thibault Gayral, David Daney, Jean-Pierre Merlet.

A collaborative work began in October 2010 with Thales Alenia Space on the calibration of the mechanical structure of a space telescope. Its architecture is based on a parallel manipulator (type active wrist 6-PUS) used to correct the relative position of two mirrors. The aim is to reach a micrometer accuracy in order to obtain a suitable quality of the images provided by the telescope. Thus, a complete model of the space telescope needs to be developed and validated through calibration. Since high velocity is not required in such an application, the dynamic effects can be neglected and only geometric and/or static calibration has to be considered.

For the geometric models, measurements for calibration were performed in a clean room under controlled pressure, temperature and humidity conditions to minimize the influence of the non-geometric errors. Thus, two possible static inaccuracy sources were identified and modeled: one from the deformation of the mobile platform and the other resulting from the behavior of the flexure joints. Three incremental models of the flexure joints were developed and compared: a spherical joint model, a model issued from the beam theory and a stiffness model. Results of calibration using an accurate measurement system of photogrammetry showed that the flexure joints can be modeled by perfect spherical joints due to the small workspace of the telescope. Concerning the mobile platform deformation, two models were developed. With those models, a positioning accuracy of some micrometers was finally reached after calibration with only position and orientation measurements of the mobile platform.

Then, opto-mechanical models were developed considering experimental measurements by imaging on the prototype of the space telescope. The optical defects were analyzed considering Zernike polynomials. The aim of optical calibration was to minimize the coefficients of the Zernike polynomials in order to improve the optical properties of the space telescope. Results of calibration were studied in order to perform a proper choice of the opto-mechanical models. Finally, the optical quality was improved after calibration. This validates the fact that the telescope can be calibrated directly in space, after its deployment, with only the provided information. A second campaign of measurements by imaging was programmed to finely adjust the opto-mechanical model parameters.

6.2. Miscellaneous results

6.2.1. Symbolic tools for modeling and simulation

Participant: Yves Papegay.

This activity is the main part of a long-term ongoing collaboration with Airbus whose goal is to directly translate the conceptual work of aeronautics engineers into digital simulators to accelerate aircraft design.

An extensive modeling and simulation platform has been designed which includes a dedicated modeling language for the description of aircraft dynamics models in term of formulae and algorithms, and a symbolic compiler producing as target an efficient numerical simulation code ready to be plugged into a flight simulator, as well as a formatted documentation compliant with industrial requirements of corporate memory.

Implementation of this platform is a modeling and simulation environment based on symbolic computation tools. It contains several components :

- a model editor, that makes it possible and easy to enter the whole set of equations describing large and complex industrial models,
- an highly interactive and modular evaluation workbench allowing to simulate the models and to visualize the results inside the modeling environment with the benefits for the designer of being able to directly use all its computational functionnalities.
- a C code generator which, using these models, automatically generates the numerical real-time simulation engines
- a technical documentation generator

Technology demonstrated by our prototype has been transferred to our industrial partner in 2012 when final version of our modeling and simulation environment has been delivered to Airbus in November 2012.

However, in 2013, we have worked on several enhancements and extension of functionnalities, namely to ease the integration of our environment into the airbus toolbox. Developer level know-how has been transferred to a software company in charge of industrialization and maintenance of the modeling and simulation environment.

6.2.2. Multi-agent aircraft design

Participant: Yves Papegay.

The modeling environment described in the previous section is used, in collaboration with other teams at Airbus, in the framework of the ID4CS project founded by ANR and dedicated to multi-agent optimization of large scale system.

Several models of aircraft engines and of aircrafts have been developed as user cases for the project.

2013 is the last year of the project when agent code based on models has been used to solve several practical optimization problems based on these models.

6.2.3. Equilibrium strategies for linked Electricity and CO2 markets

Participant: Odile Pourtallier.

In collaboration with M. Bossy (Inria -TOSCA Team) and N. Maïzi (CMA - Mines Paristech) O. Pourtallier we have pursued our work on CO2 and electricity market coupling.

The aim of this work is to develop analytic tools, in order to design a relevant mechanism for carbon markets, where relevant refers to emission reduction. In the context of electricity, the number of producers is limited, a standard game theory approach applies. The producers are considered as players behaving on the two financial markets represented here by carbon and electricity. We establish a Nash equilibrium for this non-cooperative J-player game through a coupling mechanism between the two markets.

The original idea comes from the French electricity sector, where the spot electricity market is often used to satisfy peak demand. Producers behavior is demand driven and linked to the maximum level of electricity production. Each producer strives to maximize its market share. In the meantime, it has to manage the environmental burden associated with its electricity production through a mechanism inspired by the EU ETS (European Emission Trading System) framework : each producer emission level must be balanced by a permit or through the payment of a penalty. Emission permit allocations are simulated through a carbon market that allows the producers to buy the allowances at an auction.

Based on a static elastic demand curve (referring to the times stages in an organized electricity market, mainly day-ahead and intra-day), we solve the local problem of establishing a non-cooperative Nash equilibrium for the two coupled markets.

7. Bilateral Contracts and Grants with Industry

7.1. Thales Alenia Space

Participants: David Daney [correspondant], Thibault Gayral, Jean-Pierre Merlet.

Thales Alenia Space, in partnership with the Coprin team, is studying a new concept of active space telescope. Based on a parallel architecture, its structure allows not only the telescope deployment in space but also the accurate positioning of the secondary mirror with respect to the primary one in order to improve the provided images quality. The deployment and re-positioning concepts were validated thanks to a first prototype, and the telescope performances improvement is currently under study. A first study brought to light the front-seat role of mechanical joints on the structure accuracy. However, in order to deal with the required optical accuracy and space constraints, those mechanical joints had to be replaced by flexible ones. A new prototype was then designed and built in order to validate its ability to ameliorate its images quality using flexible joints. The goal of this project is to self-calibrate the mechanical structure of the telescope: using only proprioceptive information, parameters of the robot model will be identified. Thus, a space telescope based on this concept will be able to reach its final orbit, and then to improve its image accuracy thanks to an autonomous procedure.

7.2. Airbus France

Participant: Yves Papegay.

To improve the production of numerical (flight) simulators from models of aerodynamics, Airbus France is interested in methods and tools like those described in 6.2.1.

Following the contracts signed in 2003, 2005 and 2007 with the aircraft maker, and a consulting contract in 2008 to study the possible development of an industrial tool, we have initiated in 2009 a 2-years collaboration (extended in 2012) to enhanced the functionnalities and performances of the existing pieces of software belonging to Airbus and to turn them into a prototype that integrate and showcase our results. Final version of the resulting modeling and simulation environment has been licensed to Airbus through three successive transfer agreement signed in 2010, 2011, and 2012.

Enhancements and extensions developed in 2013 have also been licensed to Airbus this year. Transfer of know-how for industrialization and maintenance has been covered by a consulting contract.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

8.1.1.1. ID4CS project

Participant: Yves Papegay.

The ID4CS project, supported by French National Research Agency (ANR) through COSINUS program has the ambition to propose a modeling and simulation environment for designing complex systems such as aircrafts, based on a self-adaptive, distributed and open multi-agent architecture distributing the optimization process inside the agents.

As a partner of the project we are mainly involved in the definition of the use case on preliminary aircraft design, in collaboration with Airbus (6.2.1), in development of uncertainty analysis algorithms, and in automatic generation of agents based on models.

8.1.1.2. COGIRO project

Participants: Julien Alexandre Dit Sandretto, David Daney [correspondant], Jean-Pierre Merlet.

We are collaborating with LIRMM, LASMEA and TECNALIA for the development of large scale wire-driven parallel robots [1]. We are especially involved in the calibration of a prototype developed by LIRMM and TECNALIA, see section 6.1.1.2.

8.2. European Initiatives

8.2.1. FP7 Projects

8.2.1.1. CABLEBOT

Type: COOPERATION

Instrument: Specific Targeted Research Project

Objective: to develop a new generation of modular and reconfigurable robots able to perform many different steps in the post-production of large-scale structures.

Duration: November 2011 - October 2014

Coordinator: Ms. Mariola Rodríguez (TECNALIA, Spain)

Partner: TECNALIA (Spain), CNRS-LIRMM, FRAUNHOFFER-IPA, UDE, Inria, EADS, ACCIONA, VICINAY

Inria contact: Jean-Pierre Merlet

Abstract: The CABLEBOT project [2] deals with a novel methodology for designing, developing and evaluating cable robots customized for the automation in large-scale auxiliary processes. Parallel cable robots extend the payloads and workspace of conventional industrial robots by more than two orders of magnitude. The main objective is to develop a new generation of modular and reconfigurable robots able to perform many different steps in the post-production of large-scale structures. Three key technologies will be developed: a) Design of Cable Robot: Software tools to design the layout and geometry of cable robots, b) Industrial Process Planning: Simulation of cable robots to verify the operation of cable robots in environments with large-scale structures c) Control Algorithms and Systems: Distributed control and kinematic transformation to operate modular cable robots. Two application examples are targeted in close cooperation to industry: aeronautical applications of maintenance and the handling of construction beams. In both cases existing automation

[1] http://www.lirmm.fr/cogiro/

[2] http://www.cablebot.eu/

can hardly be used due to maneuverability of heavy and big parts and the risk associated. The results are feasible for many other fields including large-workspace movements of products, with impact in logistics, transport, and warehousing. The exploitation and commercialization of CABLEBOT are driven by VICINAY CEMVISA, the application of industrial scenarios, two end-users of different sectors - EADS and ACCIONA - will automate their currently manual post-production. TECNALIA provides the technology for simulation in terms of productivity, cost, safety and robustness, whereas the design of the robots is in charge of LIRMM and Inria. IPA and UDE are in charge of the control algorithms, on distributed and force control of redundant systems. Benefits include an increase of production efficiency, a wider range of products, light and reconfigurable structure mechanisms and adaptable and more flexible operator assistance systems.

8.2.1.2. RAPP

Type: COOPERATION

Instrument: Specific Targeted Research Project

Objective: Robotic Applications for Delivering Smart User Empowering Applications

Duration: December 2013-December 2016

Coordinator: CERTH/ITI

Partner: CERTH/ITI(Greece), Inria, WUT (Poland), ORTELIO (UK), ORMYLIA (Greece), INGEMA (Spain)

Inria contact: David Daney, Jean-Pierre. Merlet, Manuel Serrano

Abstract: s our societies are affected by a dramatic demographic change, in the near future elderly and people requiring support in their daily life will increase and caregivers will not be enough to assist and support them. Socially interactive robots can help to confront this situation not only by physically assisting people but also functioning as a companion. The increasing sales figures of robots are pointing that we are in front of a trend break for robotics. To lower the cost for developers and to increase their interest on developing robotic applications, the RAPP introduces the idea of robots as platforms. RAPP (Robotic Applications for Delivering Smart User Empowering Applications) will provide a software platform in order to support the creation and delivery of robotics applications (RAPPs) targeted to people at risk of exclusion, especially older people. The open-source software platform will provide an API that contains the functionalities for implementing RAPPs and accessing the robot's sensors and actuators using higher level commands, by adding a middleware stack with added functionalities suitable for different kinds of robots. RAPP will expand the computational and storage capabilities of robots and enable machine learning operations, distributed data collection and processing, and knowledge sharing among robots in order to provide personalized applications based on adaptation to individuals. The use of a common API will assist developers is creating improved applications for different types of robots that target to people with different needs, capabilities and expectations, while at the same time respect their privacy and autonomy, thus the proposed RAPP Store will have a profound effect in the robotic application market. The results of RAPP will be evaluated through the development and benchmarking of social assistive RAPPs, which exploit the innovative features (RAPP API, RAPP Store, knowledge reuse, etc.) introduced by the proposed paradigm.

8.3. International Initiatives

8.3.1. Informal International Partners

Our collaboration are described in the figure 1.

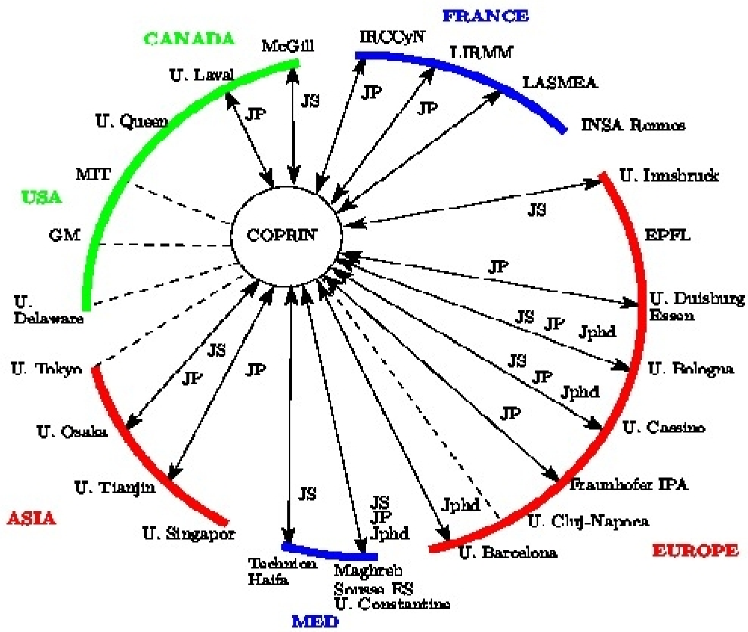

Figure 1. COPRIN collaboration. JP:joint project, JS: joint stay, Jphd: joint PhD students

9. Dissemination

9.1. Scientific Animation

9.1.1. International activities

- D. Daney has presented a paper in Computational Kinematic 2013, Barcelona, ICRA 2013 Karlsruhe and IROS 2013, Tokyo.
- D. Daney has organized and has been a member program committee of IROS 2013 workshop on Assistance and Service Robotics in a Human Environment
- J-P. Merlet is a member of the scientific committee of the European Conference on Mechanism Science (EUCOMES), chairman of the scientific Committee of the Computational Kinematics workshop, a member of the steering Committee of IROS and board member of the Journal of Behavorial Robotics. He was also a board member of the PPP Eurobotics aisbl. He is a member of the IFToMM (International Federation for the Promotion of Mechanism and Machine Science) Technical Committees on History and on Computational Kinematics and is one of the 10 members of IFToMM Executive Council, the board of this federation.
- Y. Papegay is a permanent member of the International Steering Committee of the International Mathematica Symposium conferences serie.

9.1.2. National activities

- Laurent Blanchet and Rémy Ramadour organized the JJCR (Journée des Jeunes Chercheurs en Robotique) in October 2013, and attended the JNRR (Journées Nationales de la Recherche en Robotique) in October 2013.
- D. Daney is a member of the scientific committee of the CNR SDA (Centre National de Référence Santé à Domicile et Autonomie) and of the evaluation committee of the ANR TecSan.
- D. Daney has presented the large scale initiative action PAL to JNRR 0213, Journée Nationale de la Recherche en Robotique, Annecy, to Journée Scientifique de Inria, Rennes and to the 2nd Workshop of Centre Expertise National en Robotique, Evry.
- J-P. Merlet is a member of the scientific committee of the CNRS GDR robotique

9.1.3. Inria activities

- K. Bakal is chair of the PhD students association of Inria Sophia
- D. Daney is coordinator of the Large Scale Initiative Personally Assisting Living (PAL)
- J-P. Merlet is a member of the "Bureau du Comité des Projets" of the Sophia-Antipolis Inria center.
- O. Pourtallier is a member of the CSD (doctoral students monitoring), and is responsible of the NICE committee (long term invited scientists and post-doctoral student selection).

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Licence :D. Daney gave a lecture on industrial control systems (L3), ITII, Polytech Nice (48h ETP).

Master : D. Daney gave a lecture on medical robotics, Master of Bio-Medical (M2), Univ. Nice Sophia Antipolis (22h ETP)

Master : O. Pourtallier lectured 6 hours on game theory to Master OSE (M2), at École des Mines de Paris, Sophia Antipolis, France

9.2.2. Supervision

PhD : J. Alexandre dit Sandretto, Calibration of large parallel robots, 2013, supervisors: D. Daney, G. Trombettoni

PhD :T. Gayral, Calibration of parallel telescope, 2013, supervisors: D. Daney, J-P. Merlet

PhD in progress :K. Bakal, Indices biomécaniques globaux de capacité de génération de forces, supervisor: P. Gorce (Handibio), J-P. Merlet

PhD in progress :A. Berti, Analysis of cable-driven parallel robbots, 2012-2015, supervisor: M. Carricato (U. Bologna), J-P. Merlet supervisor: P. Gorce (Handibio), J-P. Merlet

PhD in progress :L. Blanchet, Design of large scale wire-driven parallel robots, 2012-2016, supervisor: J-P. Merlet supervisors: J-P. Merlet

PhD in progress :H. Lamine, Analysis of cable-driven parallel robbots, 2013-2016, supervisor: L. Romdhane (ENI Sousse), J-P. Merlet

PhD in progress : R. Ramadour, Manipulation for assistance, 2011-2014, supervisors: F. Chaumette, J-P. Merlet

9.2.3. Juries

- David Daney has participated in in the following thesis defense committees : Jorgé Alberto Rios Martinez, January 8, University of Grenoble, France, Julien Alexandre Dit Sandretto, September 11, University of Nice, France, Thibault Gayral, November 29, University of Nice, France
- J-P. Merlet has been the member of the jury of 5 PhD defense and of one HdR

9.3. Popularization

- A short breve entitled “How Much for My Ton of CO2 ?” coauthored by Mireille Bossy (Inria TOSCA) , Nadia Maizi (CMA ENSMP) and Odile Pourtallier was published on the daily blog of MPE2013 (Mathematics for Planet Earth 2013). http://mpe2013.org/2013/07/04/how-much-for-my-ton-of-co2/
- we extensively us the `MARIONET-SCHOOL` robots for pedagogy and teaching at all level [13]. It has been exhibited at the BAUMA fair (Munich) by german colleagues, at INNOROBO (Lyon), at the JNRR (Annecy) and during the APMEP (association of mathematics professors) workshop (Marseille)
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