Activity Report 2015

Project-Team HEPHAISTOS

HExapode, PHysiology, AssISTance and RobOtics

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Robotics and Smart environments

Table of contents

Project-Team HEPHAISTOS

Creation of the Team: 2014 January 01, updated into Project-Team: 2015 July 01

Keywords:

Computer Science and Digital Science:

5.10. - Robotics
5.11. - Smart spaces
6.1. - Mathematical Modeling
6.2. - Scientific Computing, Numerical Analysis & Optimization
6.4. - Automatic control

Other Research Topics and Application Domains:

2.1. - Well being
2.5. - Handicap and personal assistances
2.7. - Medical devices
2.8. - Sports, performance, motor skills
3.1. - Sustainable development
5.2. - Design and manufacturing
5.6. - Robotic systems
8.1. - Smart building/home
8.4. - Security and personal assistance
9.1. - Education
9.10. - Ethics
9.2. - Art

1. Members

Research Scientists

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Odile Pourtallier [Inria, Researcher]

PhD Students

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Laurent Blanchet [Inria, until May 2015]
Remy Ramadour
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2. Overall Objectives

2.1. Overall Objectives

HEPHAISTOS has been created as a team on January 1st, 2013 and as a project team in 2015.

The goal of the project is to set up a generic methodology for the design and evaluation of an adaptable and interactive assistive ecosystem for the elderly and the vulnerable persons that provides furthermore assistance to the helpers, on-demand medical data and may manage emergency situations. More precisely our goals are to develop devices with the following properties:

- 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

Assistance will be provided through a network of communicating devices that may be either specifically designed for this task or be just adaptation/instrumentation of daily life objects.

The targeted population is limited to people with mobility impairments [1] and the assistive devices will have to support the individual autonomy (at home and outdoor) by providing complementary resources in relation with the existing capacities of the person. Personalization and adaptability are key factor of success and acceptance. 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.

Assistance is a very large field and a single project-team cannot address all the related issues. Hence HEPHAISTOS will focus on the following main **societal challenges**:

- **mobility**: previous interviews and observations in the HEPHAISTOS team have shown that this was a major concern for all the players in the ecosystem. Mobility is a key factor to improve personal autonomy and reinforce privacy, perceived autonomy and self-esteem
- **managing emergency situations**: emergency situations (e.g. fall) may have dramatic consequences for elderly. Assistive devices should ideally be able to prevent such situation and at least should detect them with the purposes of sending an alarm and to minimize the effects on the health of the elderly
- **medical monitoring**: elderly may have a fast changing trajectory of life and the medical community is lacking timely synthetic information on this evolution, while available technologies enable to get raw information in a non intrusive and low cost manner. We intend to provide synthetic health indicators, that take measurement uncertainties into account, obtained through a network of assistive devices. However respect of the privacy of life, protection of the elderly and ethical considerations impose to ensure the confidentiality of the data and a strict control of such a service by the medical community.
- **rehabilitation and biomechanics**: our goals in rehabilitation are 1) to provide more objective and robust indicators, that take measurement uncertainties into account to assess the progress of a rehabilitation process 2) to provide processes and devices (including the use of virtual reality) that facilitate a rehabilitation process and are more flexible and easier to use both for users and doctors. Biomechanics is an essential tool to evaluate the pertinence of these indicators, to gain access to physiological parameters that are difficult to measure directly and to prepare efficiently real-life experiments

[1] for the sake of simplicity this population will be denoted by *elderly* in the remaining of this document although our work deal also with a variety of people (e.g. handicapped or injured people, ...)

Addressing these societal focus induces the following **scientific objectives**:

- **design and control of a network of connected assistive devices**: existing assistance devices suffer from a lack of essential functions (communication, monitoring, localization,...) and their acceptance and efficiency may largely be improved. Furthermore essential functions (such as fall detection, knowledge sharing, learning, adaptation to the user and helpers) are missing. We intend to develop new devices, either by adapting existing systems or developing brand-new one to cover these gaps. Their performances, robustness and adaptability will be obtained through an original design process, called *appropriate design*, that takes uncertainties into account to determine almost all the nominal values of the design parameters that guarantee to obtain the required performances. The development of these devices covers our robotics works (therefore including robot analysis, kinematics, control, ...) but is not limited to them. These devices will be present in the three elements of the ecosystem (user, technological helps and environment) and will be integrated in a common network. The study of this robotic network and of its element is therefore a major focus point of the HEPHAISTOS 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
- **evaluation, modeling and programming of assistive ecosystem**: design of such an ecosystem is an iterative process which relies on different types of evaluation. A large difference with other robotized environments is that effectiveness is not only based on technological performances but also on subjectively perceived dimensions such as acceptance or improvement of self-esteem. We will develop methodologies that cover both evaluation dimensions. Technological performances are still important and modeling (especially with symbolic computation) of the ecosystem will play a major role for the design process, the safety and the efficiency, which will be improved by a programming/communication framework than encompass all the assistance devices. Evaluation will be realized with the help of clinical partners in real-life or by using our experimental platforms
- **uncertainty management**: uncertainties are especially present in all of our activities (sensor, control, physiological parameters, user behavior, ...). We intend to systematically take them into account especially using interval analysis, statistics, game theory or a mix of these tools
- **economy of assistance**: interviews by the HEPHAISTOS team and market analysis have shown that cost is a major issue for the elderly and their family. At the opposite of other industrial sectors manufacturing costs play a very minor role when fixing the price of assistance devices: indeed prices result more from the relations between the players and from regulations. We intend to model these relations in order to analyze the influence of regulations on the final cost

The societal challenges and the scientific objectives will be supported by experimentation and simulation using our development platforms or external resources.

In terms of methodologies the project will focus on the use and mathematical developments of **symbolic tools**(for modeling, design, interval analysis), on **interval analysis**, for design, uncertainties management, evaluation), on **game theory**, for control, localization, economy of assistance) and on **control theory**. Implementation of the algorithms will be performed within the framework of general purpose software such as `Scilab`, `Maple`, `Mathematica` and the interval analysis part will be based on the existing library `ALIAS`, that is still being developed mostly for internal use.

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.

Dissemination is also an essential goal of our activity as its background both on the assistance side and on the theoretical activities as our approaches are not sufficiently known in the medical, engineering and academic communities.

In summary HEPHAISTOS has as major research axes assistance robotics (see section 7.1.2), modeling (see section 7.2.1), game theory, interval analysis and robotics (see section 7.1). 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 assistance robotics provides realistic problems which allow us to develop, test and improve our algorithms. Our overall objectives are presented in http://www-sop.inria.fr/hephaistos/texte_fondateur_hephaistos.pdf and in a specific page on assistance http://www-sop.inria.fr/hephaistos/applications/assistance_eng.html.

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

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

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
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 HEPHAISTOS 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).

Important note: We have insisted on interval analysis because this is a **major componant** or our robotics activity. Our theoretical work in robotics is an analysis of the robotic environment in order to exhibit proofs on the behavior of the system that may be qualitative (e.g. the proof that a cable-driven parallel robot with more than 6 non-deformable cables will have at most 6 cables under tension simultaneously) or quantitative. In the quantitative case as we are dealing with realistic and not toy examples (including our own prototypes that are developed whenever no equivalent hardware is available or to very our assumptions) we have to manage problems that are so complex that analytical solutions are probably out of reach (e.g. the direct kinematics of parallel robots) and we have to resort to algorithms and numerical analysis. We are aware of different approaches in numerical analysis (e.g. some team members were previously involved in teams devoted to computational geometry and algebraic geometry) but interval analysis provides us another approach with high flexibility, the possibility of managing non algebraic problems (e.g. the kinematics of cable-driven parallel robots with sagging cables, that involves inverse hyperbolic functions) and to address various types of issues (system solving, optimization, proof of existence ...).

3.2. Robotics

HEPHAISTOS, as a follow-up of COPRIN, has a long-standing tradition of robotics studies, especially for closed-loop robots [4], especially cable-driven parallel robots. 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, 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 HEPHAISTOS works with partners on the development of real robots but also develops its own prototypes. In the last years we have developed a large number of prototypes and 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. The web pages http://www-sop.inria.fr/hephaistos/mediatheque/index.html presents all of our prototypes and experimental work.

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 [16]), 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 *modeling*, *optimal design* and *analysis* 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. Although these topics were new for us when initiating the project 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 is a long term goal. It must be reminded that we are able to manage a large variety of problems in totally different domains only because interval analysis, game theory and symbolic tools provides us the methodological tools that allow us to address completely a given problem from the formulation and analysis up to the very final step of providing numerical solutions.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Science

- strong advances on the analysis of cable-driven parallel robots (section 7.1.1)
- collaboration with lawyers on the ethical and legal aspects of robotics
- strong collaboration with the medical community on walking analysis and rehabilitation (section 7.1.2.2)

5.1.2. Experimentation

- start of an extensive test period for our walkers in clinical environment (section 7.1.2.2)
- start of the daily activities monitoring in our building (section 7.1.2.4)
- the workshop *Computer science for artists*

5.1.3. Transfer

- the contract with GénerationRobot for the development of a pedagogical cable-driven parallel robot

5.1.3.1. Awards

- J-P. Merlet has been nominated as IEEE Fellow and doctor honoris causae from University Innsbruck. He was also awarded a prize from Cote d'Azur University
- Y. Papegay was awarded the Wolfram Innovator Award

6. New Software and Platforms

6.1. ALIAS

Algorithms Library of Interval Analysis for Systems
FUNCTIONAL DESCRIPTION

The ALIAS library 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.

- Participants: Odile Pourtallier and Jean-Pierre Merlet
- Contact: Jean-Pierre Merlet
- URL: http://www-sop.inria.fr/hephaistos/developpements/main.html

7. New Results

7.1. Robotics

7.1.1. Cable-driven parallel robots (CDPR)

7.1.1.1. Analysis of Cable-driven parallel robots

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

We have continued the analysis of suspended CDPRs for control and design purposes. For control it is essential to determine the current pose of the robot for given cable lengths (forward kinematics, FK) and to be able to calculate the cable lengths for a given pose of the platform (inverse kinematics, IK). If the cables are supposed to be non-deformable the IK problem is trivial and has a single solution but the FK is complex, admits several solutions and raises several issues. We have shown in the past that to get all FK solutions for a CDPR with m cables we have to consider not only the case where all cables are under tension but also have to solve the FK for all combinations of cables under tension with 1 to m cables. Surprisingly the FK is more difficult if the CDPR has less than 6 cables under tension. Our team, in collaboration with M. Carricato of Bologna University, is the first to have designed a solving algorithm that allow to compute in a guaranteed manner all FK solutions [21], [22]. The FK problem is different if it is intended to be used in a real-time context as in that case we have the extra information of the platform pose a short time before. After a small change in the cable lengths we may assume a small change in the pose platform but using Newton method with the previous pose cannot guarantee to provide the current pose. We have proposed an algorithm that is guaranteed to get the current pose and is also able to determine if the CDPR may be sufficiently close to a singularity so that multiple solutions are possible [11]. However the assumption of a small change in the platform pose may not always hold, a point that we have shown theoretically and experimentally. We have then proposed an algorithm that uses a model of the coiling process to determine if a drastic change in the pose may occur between two sampling time [11] and also allows one to better estimate the cable tensions on a trajectory. We have for example shown that sudden and important changes in these tensions may occur. Another issue arises for non-deformable cables and CDPR with more than 6 cables in a suspend configuration. In the past we have shown that there always will be at most 6 cables under tension whatever the number of cables. For a given pose there may be several possible set of cables under tension (called *cable configuration*), each of them having different characteristics in terms of maximal tension, sensitivity to disturbances, ... From a control viewpoint it makes sense to impose a given cable configuration at the pose by setting the lengths of slack cables to larger values than the one required for the pose. To determine the best cable configuration we have proposed several ranking index [12].

Even more complex kinematic problems are involved if we assume that the cable are deformable (e.g. are elastic or catenary-like). The cable model is included in the kinematic equations for getting a complete model. We have been interested in the catenary-like model that involves inverse hyperbolic functions and is valid for steel cable of relatively high length. As the IK has never been addressed with such a model we have proposed a solving algorithm [10] that has shown that the IK may have multiple solutions but also may have no solution for poses that are reachable with non-deformable cables. In the same way the DK has several solutions [13]. Finally efficient cables interference detection for sagging cables and the management of modular CDPR, whose geometry may be changed according to the task at hand, have been addressed [9]

7.1.1.2. *Cable-Driven Parallel Robots for additive manufacturing in architecture*

Participant: Yves Papegay.

Easy to deploy and to reconfigure, dynamically efficient in large workspaces even with payloads, cable-driven parallel robots are very attractive for solving displacement and positioning problems in architectural building at scale 1 and seems to be a good alternative to crane and industrial manipulators in this area.

In a collaboration with CNAM and Ecole Nationale Supérieure d'Architecture Paris-Malaquais, we worked on additive manufacturing of building based on ultra-high performance concrete and developed a CDPR as a proof of concept to power a large scale 3D-printer.

A real size industrial robot will be developed by the XtreeE start-up company.

7.1.2. *Assistance*

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 [24], [25], [23].

7.1.2.1. *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...). We consider the assessment of upper limb capabilities by looking at the joint torques τ of the arm and the maximal force F that can be exerted by the hand, which are related by the equation

$$\tau = \mathbf{J}^{\mathbf{T}} F \tag{2}$$

where $\mathbf{J}$ is a matrix which depends only upon the configuration of the arm. These equations constitute an underconstrained linear system. In biomechanics the torque τ is measured together with the configuration of the arm and the force F is evaluated by using the method of Chiacchio, that involves the pseudo-inverse of $\mathbf{J}^{\mathbf{T}}$ to calculate F. But there are several uncertainties that are neglected when using this method: the measurement errors on τ and on the configuration of the arm together with uncertainties on the physical parameters of the arm (such as the length of the bones). The method of Chiacchio provides one of the possible solutions of equation (2) and not necessary the one corresponding to the force at the hand. We use another approach based on interval analysis. We assume that all uncertainties may be bounded (τ is an interval vector τ_m, $\mathbf{J}^{\mathbf{T}}$ is an interval matrix) so that equation (2) become an interval linear system. Interval analysis then allows one to determine an approximation as accurate as wanted of the set F_s of all forces F that satisfy the equation and therefore this set includes the real force at the hand. Now assume that with the same arm configuration we measure the force at the hand, here again with some bounded uncertainties (i.e. F is an interval vector F_m). Here again we may use interval analysis applied on equation (2) in order to determine an interval vector τ_v for the τ that is guaranteed to include the real τ. Furthermore τ must be included in the intersection τ_i of τ_v and τ_m while F must be included in the intersection F_i of F_m and F_s. If τ_i is strictly included in τ_m, then we may compute a better approximation of F_s. Reciprocally if F_i is strictly included in F_m we will get a better τ_v. If one of these situation occurs we repeat the process until no significant improvement of F_s or τ_v is obtained. In a second step we consider that the uncertainties that lead to uncertainties in the matrix $\mathbf{J}^{\mathbf{T}}$ are constrained as we have to satisfy $\tau_v = \mathbf{J}^{\mathbf{T}} F_s$. Here again we use interval analysis to determine if this constraint does not allow to reduce the size of the interval on the physical parameters in which case we may obtain a new $\mathbf{J}^{\mathbf{T}}$ that is included in the initial one. In turn this may allow to obtain better τ_v and F_s. The process stops when no improvement has been obtained for F_s, τ_v and the physical parameters.

To test this approach the right upper limb joint torque of 10 males and the force capacity at the right hand was measured by a dynamometer (Biodex III, Biodex Medical Systems) and respectively by a 6-axis load sensor during an experiment performed at HandiBio laboratory. The configuration of the upper limb was measured with a motion capture system (Qualisys, Sweden). The approach is currently being evaluated.

7.1.2.2. Walking analysis and Rehabilitation

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

The walkers of the `ANG` family allow one to determine accurately the trajectory of the walker and therefore to analyze the walking of the user. But these walkers may also be used to assess a rehabilitation process or the progress of an end-user involved in rehabilitation. For that purpose after having identified needs and requirements [17] we developed a new walker `ANG-med` that used infra-red distance sensors to measure the position of the subject during a rehabilitation exercise. Furthermore the software of this walker has been designed to support a message-passing scheme based on the HOP language of the INDES project team so that the walker may exchange information and control order with an external computer, together with allowing the download of new rehabilitation exercise through the robotics RAPP-store [26]. New exercises are designed as a set of such messages, that may include the calculation of exercise assessment indicators. `ANG-med` supports various modes: stand-alone (no external connection), passive mode (the walker only report indicator and status using a wifi connection) or full external control (an external computer fully control the walker except for emergency and real-time procedures).

ANG-med has been tested for one month in Centre Héliomarin de Vallauris and is now deployed in the rehabilitation center of MATIA in Spain, as part of the RAPP project. A start-up plan was proposed in November 2014 to transfer the walking analysis technology of HEPHAISTOS with the ANG walker in a company called Euthenia 9.2.1.3.

7.1.2.3. Design and evaluation of assistive devices, ethics

Participants: Marc Beninati, Bernard Senach [correspondant], Jean-Pierre Merlet.

Providing appropriate support, services and information to the elderly, to their caregivers and to the medical profession, through a fleet of communicating devices must rely on a structured processes. A generic design and evaluation framework is being elaborated and will be validated through field experiments [20], [19], [18].

Assistance robotics raises many ethical questions. We started reflection about conducting experiments with frail and old people. A listing of questions to be addressed at each step of an experiment has been written (internal document). We have also hired a joint PhD student with University Bologna about the legal aspects of assistance robotics and we have initiated, together with Nathalie <Nevejans from University of Douai, a meeting with the OPECST at the French National Assembly to discuss legal and ethical aspects of robotics.

7.1.2.4. Smart Environment for Human Behaviour Recognition

Participants: Aurélien Massein, Yves Papegay, Odile Pourtallier.

Both economic motivations due to demographic evolution and willingness of people to live independently at home when aging, facing physical impairment or recovering from injuries has raised the need for activity monitoring at home, in rehabilitation center or in retirement home. Monitoring systems provide information that can range from a broad measure of the daily activity to a precise analysis of the ability of a person performing a task (cooking, dressing, ...) and its evolution.

The broad range of needs and contexts, together with the large variety of available sensors implies the necessity to carefully think the design of the monitoring system. An appropriate system should be inexpensive and forgettable for the monitored person, should respect privacy but collect necessary data, and should easily adapt to stick to new needs. We aim to provide an assisting tool for designing appropriate monitoring systems.

As part of a PhD work, optimal motion planning of a mobile robot with range sensors to locate targets in a room has been studied. Work in progress also include algorithms to deploy infra-red barriers in a large area with several interest places, to be able to locate people. An experimental set-up is in use in the lab and data analysis methods are developed to infer people behaviors.

7.2. Miscellaneous results

7.2.1. 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 [14].

Technology demonstrated by our prototype has been transferred, final version of our modeling and simulation environment has been delivered to Airbus in November 2012. Developer level know-how has been transferred in 2013 to a software company in charge of industrialization and maintenance of the modeling and simulation environment.

Since 2014, we are working on several enhancements and extension of functionalities, namely to enhance the performances and the numerical quality of the generated C simulation code, and ease the integration of our environment into the airbus toolbox.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

Participant: Yves Papegay.

We had a short-term collaboration with the Exelsius company devoted to innovative solutions in processes of electronic business and namely conformal coating. Path-planning algorithms have been designed for inclusion in a new machine for selective surface activation based on atmospheric pressure plasma. Transfer of know-how has been covered by a research contract, and by a technology cession.

8.2. Bilateral Grants with Industry

Participant: Jean-Pierre Merlet.

We have got a grant from the company GénérationRobot to develop a pedagogical cable-driven parallel robot

9. Partnerships and Cooperations

9.1. Regional Initiatives

- B. Senach participated in the regional event : Workshop Santé - Maison des Sciences de l'Homme (NICE)
- project *Le refuge-Lecture: accéssibilité à la compréhension d'un texte pour des personnes en situation de handicap (auditif, visuel, cognitif)*, Conseil général projet Santé
- CPER project MADORSON for the assistance to elderly people (with the STARS project)

9.2. National Initiatives

9.2.1. Other activities

9.2.1.1. FHU

- the team has been involved for the FHU *INOVPAIN : Innovative Solutions in Refractory Chronic Pain* that has been labeled in December

9.2.1.2. Challenges and grants

- Submission to the I-Lab 2015 challenge (prize winner)
- Submission to Charles Foix Grant
- Submission to the call AUTON (CNRS) with Marc Relieu (Telecom ParisTech) (accepted)

9.2.1.3. Euthenia Start-up

Participants: Ting Wang, Bernard Senach, Jean-Pierre Merlet.

We pursued our actions to valuate technologies developed within HEPHAISTOS project team. The goal is to bring to the market an instrumented walker which provides to its users and to other stakeholder various information about walking performance. This year we proposed the creation of the Inria start-up Euthenia and we submitted to two national challenges. We won a prize for the I-Lab 2015 challenge (30 keuros) and were nominated for the Charles Foix Grant. Our Safe Walker was used as a pilot during the first Summer school of the European Institute of Technology and it was presented in Nice at the opening ceremony the Living Lab "27 Delvalle". For personal reasons the start-up is in stand-by for now but we hope to be able to reactivate it.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. 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: 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.

9.4. International Initiatives

9.4.1. Inria International Partners

9.4.1.1. Informal International Partners

We have numerous international collaborations but we mention here only the one with activities that go beyond joint theoretical or experimental works:

- University of Bologna: 2 joint PhD student, publications
- University Innsbruck: joint conference organization
- Fraunhofer IPA, Stuttgart: joint conference organization
- Duisburg-Essen University: joint conference organization
- University of New-Brunswick: 1 joint PhD student
- University Laval, Québec: joint book
- University of Tokyo: joint conference organization
- Tianjin University, China: joint book

9.5. International Research Visitors

9.5.1. Visit of International Scientists

We have received our joint PhD student J. Pickard from University of New Brunswick, K. Hanahara from Kobe University while several other scientists from other domains have visited our robotics flat.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

- 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
- Y. Papegay is a permanent member of the International Steering Committee of the International Mathematica Symposium conferences series, and member of the Program Committee of the edition 2015 held in Prague in January.

10.1.2. Scientific events selection

10.1.2.1. Reviewer

- J-P. Merlet has been reviewing Editor for IROS 2015.
- The members of the team reviewed numerous papers for numerous international conferences.

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- J-P. Merlet is board member of the Journal of Behavorial Robotics

10.1.3.2. Reviewer - Reviewing activities

- The members of the team reviewed numerous papers for numerous international journals .

10.1.4. Invited talks

- J-P. Merlet has given a talk on assistance robotics at the MESROB, a talk on cable-driven parallel robots in the workshop *robotics and biology*. He was invited to give a talk at Berkeley for the workshop *Algorithmic Human-Computer Interaction*.

10.1.5. Leadership within the scientific community

- J-P. Merlet is Inria representative to 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 has be re-elected as one of the 10 members of IFToMM Executive Council, the board of this federation. He has candidated as President of the Federation. He is a member of the scientific committee of the CNRS GDR robotique and of the CAC of UCA COMUE.
- O. Pourtallier is a board member of SeaTech, an Engineering School of University of Toulon.

10.1.6. Scientific expertise

- J-P. Merlet was an HCERES expert for Institut Pascal. He has initiated, together with Nathalie Nevejans from University of Douai, a meeting with the OPECST at the French. He was involved in project evaluations for several foreign funding agencies (Israel, Austria, Finland). He was also appointed as *Nominator* for the Japan's Prize and interviewed for challenge prizes for the European Commission's Horizon 2020 framework. National Assembly to discuss legal and ethical aspects of robotics. He was a member of the jury of the PhD Award of GDR robotique
- B. Senach participated to the Innovative City Convention (June 2015, Nice) and the 1st EIT Health Summer school (Dublin and Barcelona, July 2015)

10.1.7. Research administration

- J-P. Merlet is an elected member of Inria Scientific Council.
- Y. Papegay is a member of the Inria CUMIR and of the ADT committee
- O. Pourtallier is a member of the Inria CSD (doctoral students monitoring), and is responsible of the Inria NICE committee (long term invited scientists and post-doctoral student selection).
- B. Senach participated in the Inria communication action "Graine d'entrepreneur"

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: J-P. Merlet lectured 8 hours on robotics and connected objects to Master NeuroMoteur (M2) at University Paris Est

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

10.2.2. Supervision

PhD: A. Berti, Forward kinematics of cable driven parallel robots, supervisors: M. Carricato, J-P. Merlet [21]

PhD: L. Blanchet, Contribution to modeling of cable-driven parallel robots for command and design, University Nice Sophia Antipolis, supervisor: J-P. Merlet

PhD in Progress : A. Massein, Design of Smart Environment for Human Behaviour Recognition, 2013-2016, supervisors: D.Daney, Y.Papegay

PhD in Progress : K. Bakal, Biomechanics of the upper limb, 2013-2016, supervisors: D. Daney, J-P. Merlet, P. Gorce

PhD in Progress :M. Beninati, Legal aspect of assistance robotics, 2015-2018, supervisor: J-P. Merlet

10.2.3. Juries

J-P. Merlet has been the member of the jury of 4 PhD defense and of one HdR

10.3. Popularization

- M. Gautier has introduced robotics in a lycée in Aix
- J-P. Merlet has presented robotics assistance during an associations meeting organized by the Conseil Général. He has introduced modern robotics to 100 students of preparatory school in Cannes.
- Y.Papegay is actively participating to the Math.en.Jeans initiative for Mathematics teaching for undergraduate students. He organized and animated a summer school in experimental mathematics and computer sciences. Two one week sessions have been held in Oxford in June gathering 30 high-school students - most of them were awardees in Mathematics Olympiad
- O. Pourtallier has presented our activity to Laurence ROSSIGNOL, Secrétaire d'Etat chargée de la famille, de l'enfance, des personnes âgées et de l'autonomie

- the team has exhibited its experimental flat to about 100 visitors
- the team has organized a 5 days workshop *Computer science for artists*. Fours artists have been submitted to a crash curse on the use of sensors and actuation and have proposed a musical/dancing show the last day, based on the use of numerous motors and sensors

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