Activity Report 2017

Project-Team HEPHAISTOS

HExapode, PHysiology, AssISTance and RobOtics

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Robotics and Smart environments

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Project-Team HEPHAISTOS

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

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Other Research Topics and Application Domains:

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1. Personnel

Research Scientists

Jean-Pierre Merlet [Team leader, Inria, Senior Researcher, HDR]
Yves Papegay [Inria, Researcher, HDR]
Odile Pourtallier [Inria, Researcher]
Eric Wajnberg [INRA, Senior Researcher, from May 2017]

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Technical staff

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Artem Melnyk [Inria]

Interns

Marjorie Bonnet [Inria, Jul 2017]
Maxime Cluchague [Inria, from Jun 2017 until Aug 2017]
Axel Czarniak [Inria, Jul 2017]
Olga Melnyk [UCA, from Jul 2017 until Sep 2017]

Administrative Assistant

Laurie Vermeersch [Inria]

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 frail people [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.

[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, ...)

- **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

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, modeling (see section 7.3.1), 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 component** 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 [20]. 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. Domain

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, 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 assistance robotics [11]
- strong collaboration with the medical community on walking analysis, rehabilitation (section 7.2.1) and activities detection (section 7.2.2)
- Eric Wajnberg, an INRA senior researcher, has joined the team this year. He will bring his expertise in statistics, an element which is essential when dealing with medical problems

5.1.2. Experimentation

- preliminary test of our immersive environment for rehabilitation (section 7.2.1)
- start of the daily activities monitoring in a day hospital (section 7.2.2)

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: Jean-Pierre Merlet and Odile Pourtallier
- Contact: Jean-Pierre Merlet

6.2. PALGate

KEYWORDS: Health - Home care - Handicap

- Contact: David Daney

6.3. Platforms

6.3.1. ALIAS, Algorithms Library of Interval Analysis for Systems

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

6.3.2. Hardware platforms

We describe here only the new platforms that have been developed in 2017 while we maintain a very large number of platforms (e.g. the cable-driven parallel robots of the MARIONET family, the ANG family of walking aids or our experimental flat).

6.3.2.1. GMSIVE ADT: virtual reality and rehabilitation

Inria has agreed to fund us for developing the platform GMSIVE whose purpose is to introduce end-user motion and their analysis in a virtual reality environment in order to make rehabilitation exercises more attractive and more appropriate for the rehabilitation process. For example we have developed an active treadmill whose slope will change according to the user place in the virtual world while the lateral inclination may be changed in order to regulate the load between the left and right leg. Such a system may be used in rehabilitation to simulate a walk in the mountain while increasing on-demand the load on an injured leg (that is usually avoided by the user) for a shorter rehabilitation time. At the same time the walking pattern is analyzed in order to assess the efficiency of the rehabilitation exercise.

The motion system is composed of two vertical columns whose height may be adjusted (they are used for actuating the treadmill), a 6 d.o.f motion base and a cable-driven parallel robot which may lift the user (in the walking experiment this robot may be used to support partly the user while he is walking allowing frail people to start the rehabilitation earlier). We intend to develop sailing and ski simulators as additional rehabilitation environment. Currently the columns and motion base are effective while the robot has been installed but not tested yet and we have started to study the coupling between the motion generators and the 3D visualization.

6.3.2.2. Activities detection platform

For non intrusive activities detection we use low cost distance and motion sensors that are incorporated in a 3D printed box (figure 1) and constitute a detection station. Several such station are implemented at appropriate place in the location that has to be monitored (e.g. the Valrose EHPAD where 15 such stations has been deployed at the end of 2016 while 17 stations have been deployed at Institut Claude Pompidou at the end of 2017). Although the information provided by each station is relatively poor an appropriate network of such station allow us to provide the information requested by the medical community.

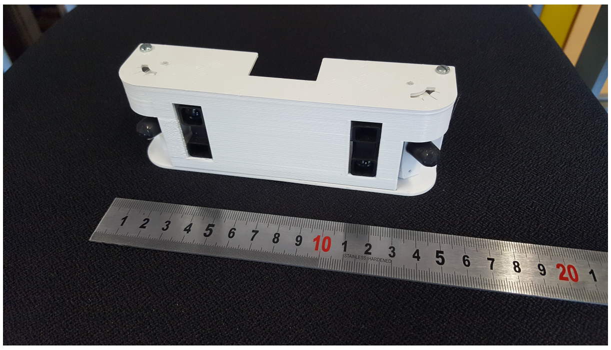

Figure 1. A station for activities detection. The 4 sensors allow to determine the presence of the subject in a given zone, his/her direction of motion and speed even at night

6.3.2.3. Instrumented cane

An alternate to the walker is using a cane for elderly support and for rehabilitation. We have developed two cane prototypes instrumented with accelerometers and force sensor (figure 2) with the purpose of monitoring the walking pattern and assess rehabilitation exercises in a more objective way. These canes have also led lights that are automatically activated at night when the cane is in motion while the ambient lightning is low with the purpose of decreasing the fall risk and to help for navigation.

6.3.2.4. Instrumented gloves

An important part of a rehabilitation process is to assess, on a regular basis, the motricity of the patient. The standard protocol for this assessment is to ask the patient to perform standardized motion while a therapist

Figure 2. Instrumented cane

puts the palm of his/her hand in opposition to measure the pressure exerted by the patient. This intuitive measurement is converted into a simplified ranking from 0 to 5 but, as mentioned by therapists, the subjectivity of this ranking is high. We have developed a glove that is able to measure the pressure and may provide a more objective assessment.

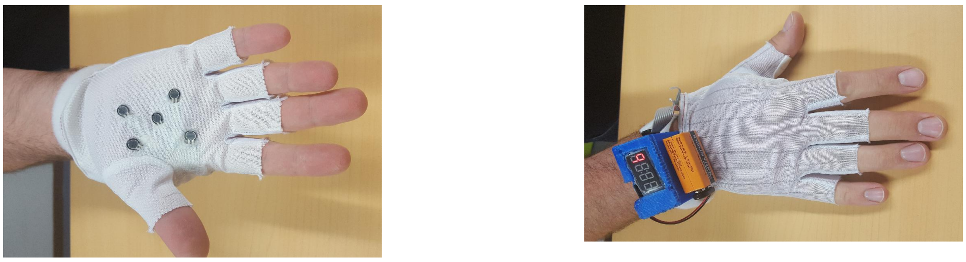

Figure 3. Instrumented glove for rehabilitation assessment

7. New Results

7.1. Robotics

7.1.1. Analysis of Cable-driven parallel robots

Participants: Alain Coulbois, Artem Melnyk, Jean-Pierre Merlet [correspondant], Yves Papegay.

We have continued the analysis of suspended CDPRs for control and design purposes. This analysis is heavily dependent on the behavior of the cable. Three main models can be used: *ideal* (no deformation of the cable due to the tension, the cable shape is a straight line between the attachements points), *elastic* (cable length changes according to the tension to which it is submitted, straight line cable shape) and *sagging* (cable shape is not a line as the cable is submitted to its own mass). The different models leads to very different analysis with a complexity increasing from ideal to sagging. All cables exhibit sagging but the sagging effect may often be neglected if the CDPR is relatively small while the sagging cannot be neglected for large CDPRs. Still even when using the ideal cable model we are contronted to complex issues. For example CDPR simulation assumes continuous time control while in reality discrete-time control is used. We have proposed a discrete-time simulation tools of CDPR [10] with surprising results (much larger tension variation in the cable, oscillation) and a complex implementation (the numerical accuracy that is required to get exact results very often exceed floating-point accuracy) that has required a very strict mathematical analysis.

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). IK for ideal cable is straightforward while more complicated for elastic cables and very complex for sagging cables. As for FK it is already complex for ideal and elastic cables while very difficult for sagging cable. We have proposed last year IK and FK solving scheme for sagging cables but they are relatively computer intensive. A major problem for the FK is that it usually provides several solutions while the control requires to determine only the solution corresponding to the current pose of the platform. A natural approach to both speed-up the FK algorithm and to get only the current pose is to add sensors on the robot. Measuring the cable tensions will be useful but has been shown to be very difficult and noisy while measuring the cable and platform orientation may be possible. But it is necessary to investigate how many sensors and their location are necessary to get a single solution for the FK: we have provided an extensive analysis of this problem for all 3 cable models [16],[17].

Last year we have investigated the calculation of cross-section of the workspace of CDPR with ideal and elastic cables, using approaches that are too computer intensive for sagging cable. We have proposed this year a preliminary algorithm for CDPRs with sagging cable that is much efficient [15] as it is based on an approximate continuation method for finding the border but it is still computer intensive. Figure 4 presents a horizontal cross-section of the workspace: the blue area are in fact the concatenation of the border of several zones that are part or are outside the workspace. In view of the complexity of the workspace border it appears that progress have to be made on that topic.

7.1.2. 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 the area of additive manufacturing.

We have co-founded 2 years ago the XtreeE (xtreee.eu) start-up company that is currently one of the leading international actors in large-scale 3D concrete printing.

We have been scientific advisors of this company for the design of an innovative new large scale CDPR - but its development, scheduled this year, has been postponed for strategical reasons.

7.2. Assistance

We are still going on in building a framework for customizable and modular assistive robotics including hardware, software and communication and medical monitoring [12]. The development of our platforms shows that we are now able to identify problematic issues for end-users, helpers and the medical community and to propose appropriate hardware/software solutions. But the most time consuming part of our work is related to evaluation and therefore experimentation: this involves legal/ethical issues (for which we contribute [11]), participation of the medical community (for evaluation and recruitment) and heavy administrative management.

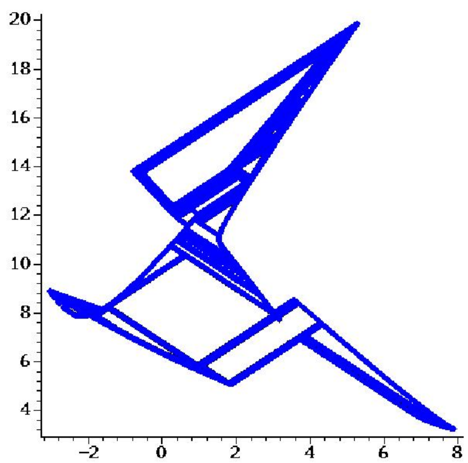

Figure 4. Cross-section of the workspace of a CDPR

7.2.1. Rehabilitation in an immersive environment

Participants: Artem Melnyk, Jean-Pierre Merlet.

Rehabilitation is a tedious and painful process and it is difficult to assess its trend. Using an immersive environment has shown to increase the patient motivation but is not sufficient regarding rehabilitation efficiency. First the visual feedback (event 3D) is not sufficient to provide a full immersive feeling as body motion is not involved. Controling body motion is also very important for therapists that currently must continuously correct the patient pose so that the rehabilitation exercise is the most efficient. We propose to add motion generators in the environment to reinforce realism (thereby increasing patient motivation) but also to allow therapists to use these generators to control the body pose so that they will be able to repeat rehabilitation exercises in a controlled context. Furthermore these generators are instrumented to provide information on the body pose and additional external sensors complete these measurements for rehabilitation assessment. We have developed 3 types of motions generators: one 6 d.o.f. motion base, a CDPR that is able to lift a patient and 2 multipurpose lifting columns. We are in the process of mixing visual feedback with these generators but unfortunately Inria-Sophia immersive room that we were planning to use is no more available. Hence we have been obliged to develop a renderer and this has slowed down the integration process. Still we have currently a preliminary experiment going on: our columns are able to modify the slope and inclination of a treadmill so that we can simulate a walk in the mountain while controlling the inclination to enforce the use of one specific leg. External and wearable sensors allow us to monitor the walking pattern and provide synthetic indicators on this pattern for the therapist.

7.2.2. Smart Environment for Human Behaviour Recognition

Participants: Mohamed Hedi Amri, Alain Coulbois, Aurélien Massein, Artem Melnyk, Jean-Pierre Merlet, Yves Papegay, Odile Pourtallier, Valérie Roy, Eric Wajnberg.

The general aim of this research activity focuses on long term indoor monitoring of frail persons. In particular we are interested in early detection of daily routine and activity modifications. These modifications may indicate health condition alteration of the person and may require further medical or family care. Note that our work does not aim at detecting brutal modifications such as faintness or fall.

In our research we envisage both individual and collective housing such as rehabilitation center or retirement home.

Our work relies on the following leading ideas :

- We do not base our monitoring system on wearable devices since it appears that they may not be well accepted and worn regularly,
- Privacy advocates adequacy between the monitoring level needed by a person and the detail level of the data collected. We therefore strive to design a system fitted to the need of monitoring of the person.
- In addition to privacy concern, intrusive feature of video led us not to use it.

The main aspect that grounds this work is the ability to locate a person or a group in their indoor environment. We focus our attention to the case where several persons are present in the environment. As a matter of fact the single person case is less difficult.

A natural way of being able to adapt the accuracy of localization (and consequently accuracy of monitoring), is to use a partition of the monitoring area in a finite number of elementary zones ; the number of zones together with their geometry being closely related with the pursued level of monitoring. In practice these zones will be materialized by sensors barriers that detect the passage of a person from one zone to another. Henceforth each zone are polygonal.

We are following several directions :

- monitoring system design,
- material development,
- data gathering and analysis,
- experimentation.

7.2.2.1. Monitoring system design

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.

There is an ongoing PhD work about to be defended : metrics have been defined to evaluate quality of sensors solutions and placement to infer people behaviors inside a smart environments, and a methodology for optimal design of smart environments has been developed.

7.2.2.2. Material development, signal processing and data fusion

Based on the experimentation we initiated in 2016 in Ehpad Valrose and this year at the Institut Claude Pompidou in Nice, we designed, developed and tested a new class of multi-sensors barriers to overcome difficulties arising from wider environment, reflection properties of walls and light exposures.

These multi-sensor barriers contains a selection of infra red distance sensors and motion sensors of passive infrared type. Dedicated signal processing, and fusion of the different sets of signals provide information on crossing time, direction of crossing, speed and size of crossing person, object, or group. This last information is helpful to differentiate for example a person using a wheelchair, a valid person (e.g medical staff), or an elderly.

7.2.2.3. Data analysis for activity recognition

Data are issued from long-term recording during on-going experimentation and from simulation tools developed on purpose from probabilistic models.

At Ehpad Valrose, a monitoring system is installed since last year in the first floor. Area of monitoring is restricted to the hallway that leads to the individual rooms of six residents. Residents are proposed several activities (social or cultural activities, physical activities, meals) and have to use the hallway when participating to those activities. Hence few people are entering the experimentation area, with significant characteristics : elderly with rolling chairs or rollators, autonomous elderly, technical staff with trolleys, visitors, caregivers. On this experiment, we focus our analysis on inferring from data, quantitative indicators on the activity of each resident. Data analysis generates several possible scenarii of activities. They are discriminated, based on distinction of people when crossing barriers and on additional knowledge on their habits.

7.2.2.4. Experimentation

A new monitoring system has been installed in Institut Claude Pompidou in Nice. Area of monitoring is an half floor dedicated to a consultations and day care unit of the Centre Mémoire de Ressources et de Recherche, together with a clinical research unit of the Cobtek team. It consists in 15 rooms articulated on a simple network of hallways, including offices, training rooms, consultation rooms, waiting area, toilets, resting room for staff, delimited by an entrance and a communication to the research center. Patients, service staff, clinical staff, researcher are using the monitored area. The aim of this experiment is to determine identify the different flows of people between different zones to qualify uses of the facilities and interaction between the different groups of users.

Twenty barriers have been installed for a total of 77 sensors and kilometers of cable deployed. Installation and set-up of the system led to several electrical, electronical and technical problems, efficiently solved by the engineers of our group that played a crucial role.

7.3. Miscellaneous results

7.3.1. 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 - MOSELA - 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.

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

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.

In 2016, we continued our integration effort of connect the MOSELA environment with other Airbus modeling tools.

A study has been launched to guarantee that the result of simulation performed by the generated C code is not dependent on the description order of the equations in the model.

8. Bilateral Contracts and Grants with Industry

8.1. Airbus

Participant: Yves Papegay.

Results of research activities on MOSELA environment have been transferred by a contract with Airbus company.

8.2. Ellcie Healthy

Participants: Alain Coulbois, Jean-Pierre Merlet.

A contract has been granted for the evaluation of the performances of connected glasses that are developed by this company.

9. Partnerships and Cooperations

9.1. Regional Initiatives

- CPER project MADORSON for the assistance to elderly people (with the STARS project)
- the project REVMED involving Hephaistos and the CHU team CobTeK has been funded by the local IDEX. It will allow us to continue our work on rehabilitation in an immersive environment.

9.2. National Initiatives

9.2.1. FHU

- the team has been involved for the FHU *INOVPAIN : Innovative Solutions in Refractory Chronic Pain* that has been labeled in December 2016

9.3. International Initiatives

9.3.1. Inria International Partners

9.3.1.1. 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

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. Member of the Organizing Committees

- 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. He is a member of the OpenMath Society, building an extensible standard for representing the semantics of mathematical objects

10.1.2. Scientific Events Selection

10.1.2.1. Reviewer

- J-P. Merlet has been reviewing Editor for IROS 2017 and was a member of ICRA 2017 IPC.
- 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

10.1.4. Invited Talks

- J-P. Merlet was invited by the Royal Society of Edinburgh for a talk on robotics

10.1.5. Leadership within the Scientific Community

- J-P. Merlet is Inria representative to 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 has be re-elected as one of the 10 members of IFToMM Executive Council, the board of this federation. He is a member of the scientific committee of the CNRS GDR robotique.

10.1.6. Scientific Expertise

- J-P. Merlet was involved in project evaluations for several foreign funding agencies (Israel, Austria, Finland). He was also appointed as *Nominator* for the Japan's Prize.

10.1.7. Research Administration

- J-P. Merlet is an elected member of the Academic Council of UCA COMUE and member of the Research, Ethical Committees of UCA
- O. Pourtallier is a board member of SeaTech, an Engineering School of University of Toulon.

10.1.7.1. Inria activities

- J-P. Merlet is an elected member of Inria Scientific Committee
- O. Pourtallier is responsible of the NICE committee (long term invited scientists and post-doctoral student selection).
- Y. Papegay is a member of the Inria CUMIR and of the ADT committee

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

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 in Progress : A. Massein, Design of Smart Environment for Human Behaviour Recognition, 2013-2018, supervisors: D.Daney, Y.Papegay

10.2.3. Juries

- J-P. Merlet has been a member of 5 PhD juries
- Y. Papegay has been a member of 1 PhD jury

10.3. Popularization

- J-P. Merlet and A. Coulbois participated to Inorobot and several other events, exhibiting a cable-driven parallel robot for education
- J-P. is a member of the Scientific Committee managing the future permanent exhibition on robotics at the Cité des Sciences, Paris
- Y.Papegay is actively participating to the Math.en.Jeans initiative for Mathematics teaching for undergraduate students.
- Y.Papegay organized and animated summer schools in experimental mathematics and computer sciences. Several one week sessions have been held in Oxford in June, July, August and November gathering more than 70 high-school students - most of them were awardees in Mathematics Olympiads.

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