RESEARCH CENTRE

Inria Centre at Université Côte d'Azur

2024

ACTIVITY REPORT

Project-Team

HEPHAISTOS

HExapode, PHysiology, AssISTance and RobOtics

DOMAIN

Perception, Cognition and Interaction

THEME

Robotics and Smart environments

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Project-Team HEPHAISTOS

Creation of the Project-Team: 2015 July 01

Keywords

Computer sciences and digital sciences

A5.1. – Human-Computer Interaction

A5.10. – Robotics

A5.11. – Smart spaces

A6. – Modeling, simulation and control

A6.1. – Methods in mathematical modeling

A6.2. – Scientific computing, Numerical Analysis & Optimization

A6.3. – Computation-data interaction

A6.4. – Automatic control

A6.5. – Mathematical modeling for physical sciences

A8.4. – Computer Algebra

A8.11. – Game Theory

A9.2. – Machine learning

A9.5. – Robotics

A9.6. – Decision support

A9.7. – AI algorithmics

A9.9. – Distributed AI, Multi-agent

A9.10. – Hybrid approaches for AI

Other research topics and application domains

B1.1. – Biology

B2.1. – Well being

B2.5. – Handicap and personal assistances

B2.7. – Medical devices

B2.8. – Sports, performance, motor skills

B3.1. – Sustainable development

B3.5. – Agronomy

B4.5. – Energy consumption

B5.2. – Design and manufacturing

B5.6. – Robotic systems

B5.7. – 3D printing

B8.1. – Smart building/home

B8.4. – Security and personal assistance

B9.1. – Education

B9.2. – Art

B9.4. – Sports

B9.6.10. – Digital humanities

B9.9. – Ethics

B9.10. – Privacy

1 Team members, visitors, external collaborators

Research Scientists

- Yves Papegay [Team leader, INRIA, Researcher]
- Jean-Pierre Merlet [INRIA, Emeritus]
- Odile Pourtallier [INRIA, Researcher]
- Eric Wajnberg [INRAE - convention with Inria, Senior Researcher]

PhD Students

- Clara Thomas [INRIA]
- Romain Tissot [INRIA]

Interns and Apprentices

- Sara Gabaldo [INRIA, Intern, from Sep 2024]

Administrative Assistant

- Jane Desplanques [INRIA]

2 Overall objectives

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

[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, ...)

- **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 [10] 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 and 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 focuses 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 ones 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 that 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 due to its background both on the assistance side and on the theoretical activities : our approaches are not sufficiently known in the medical, engineering and academic communities.

In summary, HEPHAISTOS has as major research axes assistance robotics, modeling, game theory, interval analysis, robotics and AI (see section 8.1). The coherence of these axes 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 this document and in a specific page on assistance.

3 Research program

As seen in the overall objectives, managing uncertainties is a key point of our research. In the health domain, uncertainties are managed with statistics (which explains partly the presence of Eric Wajnberg in our team) but statistics just give trends while in some cases we will be more interested in the worst case scenario. Interval analysis is an approach that can be used in that case and we constantly improve the foundations of this method.

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 exists 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 $\{x_1, x_2, \ldots, x_n\}$ and ranges $\{X_1, X_2, \ldots, X_n\}$ for these unknowns, we are able to compute a range $[A, B]$, called the interval evaluation, such that

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

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

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

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 $x_1, x_2, \dots, x_n$ such that $F(x_1, x_2, \dots, x_n) = A(B)$ 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 as 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 $F(\mathcal{B}) \ge 0$ for a certain box $\mathcal{B}$).

A generic interval analysis algorithm involves the following steps on the current box [13, 4]:

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 verify 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 ...). However, whenever needed, we will rely as well on statistics, continuation, algebraic geometry, and since a couple of years on AI.

3.2 Robotics

HEPHAISTOS, as a follow-up of COPRIN, has a long-standing tradition of robotics studies, especially for closed-loop robots [9], 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 [11].

Our theoretical work must be validated through experiments that are essential for the sake of credibility and, a contrario, experiments will feed our 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 page presents all of our prototypes and experimental work. Note that this familiarity with hardware is also used from time to time to develop devices for others INRIA projects and, during the Covid crisis, our building was instrumented for accurately monitoring CO and CO2 level well before it became the norm.

4 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 and biology), 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, doctors, family and caregivers, institutes), establishing strong collaboration with them (e.g. with the CHU of Nice) and putting together an appropriate experimental setup for testing our solutions.

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 with 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. Hence although we mainly focus on medical and assistance robotics we address also a large number of applications: agriculture, biology, arts, system design to name a few.

5 Social and environmental responsibility

5.1 Footprint of research activities

Clearly our activities have a negative impact on the environment (travels, hardware orders, ...). Although Sophia-Antipolis is not the best place regarding national travels, we have decreased our national and international travel activities while having reduced our global impact at work in different manners (lighting, work mobility, ...). Still we must emphasize that all aspects of our impact have to be taken into account before coercive measures are taken. For example, when we travel to a retirement house to install assistive devices, the footprint impact has to be balanced with our social impact and finding the right compromise is not an easy task and the choice is not the responsibility of the team alone. Furthermore human relationships are essential for initiating new research areas and for the time being virtual collaborations and conferences are not very effective for that purpose.

5.2 Impact of research results

Our works on assistance clearly may have a social impact and we are deeply aware of our ethical responsibilities as illustrated by the activity of the team in ethical committees, our collaboration with the academic law community and our large dissemination effort toward the general audience.

Regarding environmental responsibility, energy has been since the very beginning of our project an important topic in our research. Indeed our assistance/health monitoring devices require additional energy source and elderly people may have some difficulties to deal with battery charging. Consequently, since the beginning of the project, we have focused on low consumption electronic components and most our devices use mechanical energy converter or solar panel to produce most of the energy they need. However the intended benefits of these devices on health, self-esteem and dignity (all issues that are difficult to measure/compare in pure financial terms or with respect to environmental impacts in all their dimensions) have to be taken into account.

6 Highlights of the year

6.1 Scientific highlights

In 2024, several research activities that started earlier have been extensively developed with the help of our PhD students:

- on preventive maintenance of cable driven-parallel robots
- on green robotics.

A nice achievement is the generalization of the work previously done on application of artificial intelligence to kinematics of cable driven-parallel robots. It has led to the development of an hybrid solver of parametric non linear square system of equations mixing neural networks and numerical iterative schemes.

New activities have been launched as well with related new collaborations:

- on modeling and simulation of underconstrained cable driven-parallel robot,
- on the use of artificial intelligence for kinematics modelling of soft robots,
- on the use of networks of conversational agents for planification and control of robots tasks.

7 New software, platforms, open data

7.1 New software

7.1.1 PSOLVER

Name: Parametric equations solver with IA

Keywords: Numerical solver, Artificial intelligence

Functional Description: This solver mixes supervised deep learning and deterministic methods to obtain exact solutions (i.e. the differences between the provided solutions and the real ones may be arbitrary small). It cannot guarantee to find all solutions but it has a self-learning capacity so that the probability of missing a solution is very low. The solver is based on the predictions of several neural networks that are used as guess for the Newton scheme so that the solving time is low, usually around a few milliseconds. The computer intensive part for establishing the solver is the training of the neural networks using automatically generated learning sets. It shall be used only if the system has to be solved for multiple occurrences of P.

Contact: Jean-Pierre Merlet

8 New results

8.1 Robotics

Participants: Jean-Pierre Merlet *(correspondant)*, Yves Papegay, Clara Thomas, Romain Tissot.

8.1.1 Preventive maintenance of cable driven-parallel robots

Participants: Jean-Pierre Merlet *(correspondant)*, Romain Tissot.

The cables of a cable-driven parallel robot (CDPR) follow a path through several mechanical elements that lead to a progressive wear of the cable. As CDPR may be used to assist frail people to walk, for rehabilitation purpose or in industry (e.g. logistic), it is important to estimate the cable wear in order to avoid a situation where a cable may break down. Our objective is therefore predictive maintenance where trends will be estimated for the wear in order to allow to change the cable(s) before a breakdown. Classical cable models involve the Young modulus E and the linear density μ of the cable material. The Young modulus reflects the elasticity of the cable (i.e its length change when submitted to a tension) and we have estimated that wear will mostly affect it by decreasing its value compared to its value E_b when the cable is brand new.

For a given pose $\mathbf{X}$, we can compute the cable lengths L_0 under the assumption of known Young modulus for all cables. Wear in cable(s) will decrease E so that the cable lengths will increase which in turn will change the pose $\mathbf{X_m}$ that the robot will reach. As we have means to measure accurately the pose (or part of it) we have simulated the difference $\mathbf{X}-\mathbf{X_m}$ for different calibrations poses and we have shown that, if E goes below $E_b/2$, the difference is big enough to be measured. We have then addressed the inverse problem where $\mathbf{X}-\mathbf{X_m}$ is measured for different calibrations poses, the objective being to estimate the Young modulus of the cables. We have shown that it is possible to find calibration poses where only a pair of cables are supporting the load (the other being slack) and we have developed two approaches to estimate the Young modulus of this pair of cables:

1. an adapted gradient descent algorithm which has been derived from our work on the inverse kinematics of CDPR (where an optimality criterion has to be defined under the constraints that kinematic equation have to be fulfilled) [19]

2. an IA based approach, derived from our work on the inverse kinematics of CDPR [20]

The first algorithm is rather slow (about half an hour for a cable pair) but provides almost exact estimation of E while being reasonably robust with respect to measurement errors. The second algorithm is very fast (almost real time) but provides more approximate values for E and is more sensitive to measurement errors. However these results may be improved by creating several neural networks that will be specialized to deal with specific ranges for the values of E.

Hence wear estimation is in theory feasible at a low cost but an experimental validation of this result requires very specific equipment for measuring the Young modulus of the cables at different times that are not available to us.

The PhD defense of Romain Tissot presenting some of this work has been held on December 13 [22].

8.1.2 Parametric equations solver with IA

Participants: Jean-Pierre Merlet.

Our work in robotics has led us to investigate the use of IA for finding the real root(s) of parametric non linear square system of equations $\mathbf{F}(\mathbf{X},\Lambda) = \mathbf{0}$ i.e. systems which have as many unknowns $\mathbf{X}$ as equations but with equation coefficients that are functions of a parameters set Λ that is assumed to be bounded. Such a system has usually several solutions and their number depends on the parameters values and cannot be determined in advance. The equations must have an algebraic analytic form, not being differential and being at least $C1$.

Our robotics work has shown that as soon as we are able to determine the solutions (not necessarily all of them) for a small set $\Lambda = \{\Lambda_1, \dots \Lambda_n\}$ of specific systems, then we may create an hybrid solver mixing Multi-layer Perceptrons (MLPs) and the Newton scheme that provide solutions for any Λ. This solver requires the training of multiple MLPs and the training time may be large. However, as soon as the training is completed, the solving time is extremely low (typically less than 0.02 seconds). We cannot guarantee to obtain all solutions (although extensive tests have shown that in general we will miss very few solutions). Furthermore an associated self-learning process may allow to reduce the number of missed solution(s) as soon as new system instances are solved. This year we have extended this approach to arbitrary system [15]. A first version of the corresponding prototype Psolver is presented in the new softare section 7.

8.1.3 Kinematics of soft robots and AI

Participants: Jean-Pierre Merlet.

There is a growing interest in *soft robots* for which the links are made of flexible material, many of which have a closed-loop structure (typically like parallel robots). This community has focused on the modeling of the links in various forms and their use for basic kinematic problems such as finding an inverse kinematic solution and starting from this solution finding a new pose for a given set of actuators positions. But these problems are already computer intensive, which prohibits to address more complex issues such as computing the robot workspace, finding all solutions of the direct kinematics or solving design problem (e.g. determining the geometry(ies) of the robot so that all poses in a given workspace are reachable). We have started cooperating with researchers in this domain to see if an IA-based solver may be developed for the inverse and direct kinematics that are the basic tools that may be used to solve these complex problems.

8.1.4 Green robotics

Participants: Jean-Pierre Merlet, Yves Papegay, Clara Thomas *(correspondant)*.

About 40% of the 4 000 000 existing robots are performing manutention operations and about half of them are performing repetitive pick-and-place task where an object has to be moved from A to B.

This motion usually involves only 3 translational degrees of freedom and possibly a rotation around the vertical axis.

For this operation, several types of mechanical architecture are used: serial, cartesian and Scara types. These architectures are not energy efficient as their structure imposes to actuate several heavy mechanical elements beside the load (e.g the serial type require energy just to stay in its pose). Furthermore these robots are controlled with a rather powerful computer as they may be used for other purposes and these systems use a lot of mechanical and electronic resources while being not very flexible and difficult to maintain. All in all, this amounts to a large energy consumption and an extensive use of resources for a simple task. Our objective is to propose a specific robot for this task with a much lower energy consumption, less resources and being simple to maintain and offering a larger flexibility.

The first step of our proposal is to adopt a different mechanical architecture based on cable-driven parallel robots. They have multiple advantages:

- they involve only a very limited mobile mass as only the cables are moving
- they are highly flexible: just by moving the winches, it is possible to cover any kind of workspace even very large ones (the FAST telescope covers a circular area of 500 m of diameter),
- their lifting capacity may be very high (our *Marionet-crane* has a lifting capacity of 2.5 tons),
- they are easy to maintain either by just changing the cables or the winches that are fairly standard,
- the energy efficiency or parallel robots is, in general, 25% higher than any other robot structure.

CDPR may be designed for various degrees of freedom but the simpler one, called the *N-1* CDPR, has N cables attached at the same point on the platform. This CDPR offers either planar motion with the 2-1 ($x-z$ motion) or spatial motion with the 3-1 and 4-1 (the difference being a larger workspace for the 4-1). The platform may provide an independent rotation motion if necessary.

To check the energy efficiency of a CDPR, we have built a 2-1 CDPR and we have defined a classical pick and place trajectory (a vertical upward motion from A, an horizontal motion toward B and a vertical downward motion at B) and we have measured its energy consumption over 500 trajectories. In parallel colleagues at INRIA Bordeaux are measuring the energy consumption of a serial robot for the same load and the same trajectory. Tests have not yet been fully completed but preliminary results show that the CDPR has an energy consumption which is between 500 and 1000 less than the serial robot. In parallel, we have built two small pieces of software for estimating the power consumption of 2-1 and 3-1 CDPR: one is based on a full theoretical model of the system and the other one on experimental measurements on the motor behavior that has allowed us to have an experimental model of the system. Both software have been used to evaluate the power consumption of our 2-1 prototype and the estimations are in very good agreement with the measured consumption. These models can also be used for the 4-1 with an additional complexity: in general a 4-1 has at most 3 cables simultaneously under tension (and in some special cases only 2) but for a given pose two different sets of three cables, called *configurations*, may be under tension each of which lead to a different power consumption. Enforcing a configuration for a given pose is easy (we just increase the length of the fourth cable) but at some points, called *transition points*, a set of 3 selected cables under tension cannot anymore ensure the mechanical equilibrium of the system and we have to move to another configuration hence realizing a *configuration change*. For a given polygonal trajectory, each segment may be decomposed in different sub-segments for which only 3 specific cables are under tension. This decomposition leads to multiple ways to realize the trajectory with different configurations. Our simulation software allow us to determine the way that leads to the minimal energy consumption (and we may also deal with the same problem but with a minimal number of configuration changes). We have also investigated the influence of the height h of the winches and shown that the energy consumption decreases with h. For the 4-1 where the winch locations lies on the corner of a square whose side length is a, we have shown that the consumption decreases with a (which has however a minimal value as the trajectory has to be enclosed in the square).

A drawback of suspended 2-1, 3-1 and 4-1 CDPR is the load oscillation. This problem may be limited by having a pair of cables on each winch exiting at two output points A_1, A_2 and attached at two points on the platform B_1, B_2 such that $||\mathbf{A_1A_2}|| = ||\mathbf{B_1B_2}||$ and consequently the quadrilateral $A_1B_1B_2A_2$ is a parallelogram whose side B_1B_2 is always parallel to A_1A_2. For the 2-1 this prohibits oscillation around the perpendicular to the CDPR plane while for the 3-1 and 4-1 all oscillations are avoided.

Regarding energy consumption we are still using a computer to control our CDPR although a low power computer may be used (a Raspberry Pi is largely sufficient) and electronic resources to control the robot motion and the objective is to get rid of this computer. For a N-1 CDPR, it is easy to determine the cable lengths time functions $\dot{\rho}(t)$ to execute a trajectory at a given speed. At any time we may convert $\dot{\rho}(t)$ to a distance $d(t)$ from a point M to a fixed point U as $d(t) = \dot{\rho}(t)/k + d_0$ where k is an arbitrary amplification factor. Assume now that we have created a rotating came and have a slider that measure the distance between the contour and a fixed point N located on the vertical: this cam may designed so this distance is exactly equal to d at any time. Consequently, if the slider actuates a potentiometer, its tension may be used as velocity input for a motor controller that will actuate the winch and, with a cam for each cable, the CDPR will perform the trajectory at the desired speed up to a fixed gain. Consequently we have gotten rid of the computer and some electronic resources and have just added the energy consumption of a small motor that actuate the cable cams. We have not lost the possibility of programming the trajectory as new cams may easily be 3D-printed. Note that the cam may be designed to offer the possibility of moving from A to B and then back to A so that the cam will just rotate continuously.

We are also considering the case where the sliders will directly actuate the winches, using a single motor: we will be back to a mechanically programmable robot using a single motor !

This work on using CDPR geometrical modularity to minimize energy consumption will play a role for the second part of C. Thomas thesis that will be managing the modularity of a 4-1 CDPR devoted for facilitating the mobility of frail people. A fixed geometry CDPR allows only for mobility in a single room but we plan to use the geometrical modularity of CDPR to allow to use a CDPR with only four fixed winches in several rooms.

8.1.5 Underconstrained CDPR

Participants: Sara Gabaldo, Jean-Pierre Merlet *(correspondant)*.

Underconstrained CDPR have less cables than the platform degrees of freedom (dofs). Typically we can consider a CDPR with 3 cables that are attached to three different points of the platform: they allow to control only three of the platform six dof but any combination of 3 dof among the 6 may be controlled and this may be interesting for some industrial tasks with the advantage of reducing the cost.

In a joint work with the laboratory IRMA of Bologna University, we are addressing the following problem: being given a translational trajectory for the platform that has to be performed at a given velocity, what should be the geometry of the CDPR so that the angular motion of the platform remains in a given bounded domain while the maximal distance between the desired trajectory and the followed one should be lower than a fixed threshold ?

We have to consider that a given CDPR, which is velocity controlled with a discrete-time control law, cannot follow exactly the trajectory and hence both the maximal positioning error with respect to the trajectory and the maximal angular motion are functions of the controller sampling time, of the desired speed and of the CDPR geometry but it is very difficult to establish analytic values for these maximum as functions of the parameters. However, being given a nominal trajectory, we have been able to design a continuation software to fully simulate the CDPR motion in this context and are working on a fast method to provide an upper bound on the positioning errors and on the amplitude of the angular motions. This software could be extended to deal with uncertainties on the CDPR geometry with the objective of providing worst case upper bounds. A brute force approach may then be used to determine good geometries.

8.1.6 Networks of conversational agents and robots

Participants: Yves Papegay.

The use of Large Language Models (LLMs) in robotics is an emerging trend. These new natural language processing capabilities aim to improve the induction of high-level robot behavior. The proposed approach relies on conversational agents organized in graphs, a powerful, modular, and flexible method that leverages LLMs to interpret and contextualize commands while integrating classical components for motion planning, dynamic environment control, or object manipulation. The first challenge is to reliably transform descriptions of the environment, instructions, or constraints expressed in natural language into a functional decomposition of robotic tasks. This requires combining the contextualization provided by LLM embedding mechanisms with access to factual information about the environment, whether dynamic (from sensors) or static. A second challenge lies in the increasing complexity of agent organization, which grows with the complexity of the tasks to be managed. This organization must dynamically adapt to changes in the robots' behavior or capabilities while ensuring the correct execution of tasks. With specialized agents possessing domain expertise, these technologies promise to enhance robots' ability to adapt to complex situations and provide robust solutions to the application problems encountered.

This new explorating work is done in collaboration with David Daney (Auctus team, centre Inria de l'Université de Bordeaux).

8.2 Human activity recognition and analysis

Participants: Yves Papegay *(correspondant)*, Odile Pourtallier.

The context is the recognition and analysis of human activities indoors using data from non-intrusive sensors (measuring light or water consumption namely). We are particularly interested in evaluating autonomy criteria for elderly or weakened individuals, such as mobility, hygiene, or social connection. It is important for us to associate this evaluation with a confidence index by considering the reliability of the data used, the uncertainty attached to it, and the consistency of the information it allows us to infer.

The process of producing guaranteed relevant information from uncertain measurements involves a series of steps: acquisition, validation, consolidation, fusion, interpretation, classification, and analysis. These steps involve both signal processing methods and data analysis algorithms from statistics, modeling, and artificial intelligence. Our theoretical objective is to develop a generic environment, formalism, and methodology around this process. Our practical goal is to detect weak signals of anomalies or changes in the produced information within the noisy temporal data.

The expected impact of detecting these signals is to anticipate an abnormal situation or indicate a slow evolution, such as a slight increase in water consumption indicating a leak, or a slight decrease in activity that may suggest the onset of locomotor deficiency.

Quality of life related to health, aging well, anticipation of the loss of autonomy of elderly people, the importance of environmental factors, and particularly the living environment in health determinants are all identified targets for the experimentation and validation of our methods and results. These are key concepts at the heart of public health policies and the issue of population aging, with its new economic, technological, and societal challenges.

8.2.1 Movements characterization with smart barriers

As human activities often rely on mobility, a central issue is the monitoring and characterization of the movements of a person or a group of people within a building. In the previous years, we have chosen to develop and use virtual barriers that record the date, direction, and an estimate of the speed of their crossings.

Thanks to available funding for equipment, we have been able to make progress simultaneously on experimentation (both hardware and algorithmic aspects) and on system design methods and information processing. We have set up two experiments, the first in a corridor serving rooms, offices, and consultation rooms at the Valrose EHPAD in Nice, and the second in a day hospital treating patients suffering from Alzheimer's disease, in Nice as well. In these past experiments (conducted over several months, 24 hours a day), we have recorded a significant number of barrier crossings.

Currently, the information extracted by merging sensor data allows for the generation of barrier-crossing instances and provides a certain characterization by indicating the direction and a rough estimate of the person's speed of movement. However, visual inspection of the various data allows for the identification of additional characteristics such as crossings by a wheelchair, the use of a cart, crossings by a group of people, and their proximity. Furthermore, the use of contextual data associated with the measurements allows for further refinement of the information regarding people's behavior.

This leads us to explore how AI methods can be used to more reliably and automatically characterize crossings and to leverage contextual data. These methods could also enable real-time monitoring and analysis, which our current work does not allow.

8.2.2 Smart digital liaison notebook

For seniors, aging well means staying as healthy, active, and independent as possible in their own home. However, when the loss of autonomy and dependency begins, if the person is isolated, remaining at home is complex: it requires the establishment of an ecosystem organization around them, including family, close friends, caregivers, and healthcare providers. Within this heterogeneous group, communication and sharing of daily information are crucial for the proper functioning and effectiveness of this organization, as well as for ensuring the peace of mind of both the individual and their family by demonstrating this proper functioning. Continuing developments made during the technological maturation of the startup creation project LOCANAC in 2022, we are working on a Web/Mobile application that serves as a communication and information-sharing tool, an 'intelligent' digital liaison notebook. This application has three main functionalities:

- Collect: Offer an ergonomic and accessible human-machine interface on a smartphone or tablet for the input of impressions, testimonies, and facts by caregivers, healthcare providers, visiting relatives, and possibly the senior themselves. Provide software interfaces and an automated connection mechanism to collect potential environmental data from servers (fluid consumption, weather, etc.), data from possible home automation sensors, or wearable sensors.
- Analyze and Synthesize: Reliably produce, from the collected data and its temporal tracking, a set of standard indicators of autonomy, activity, physical and mental well-being, and quality of life related to health,
- Share: Provide the individual and their family with a dashboard of the organization in place for aging well, showing its proper functioning, the state of the community, and the individual. Make available to each member of this community the information they need to be effective and that the elderly person is willing to share with them.

8.3 Biology activities

8.3.1 Impact of parasitoids on an invasion process

Participants: Yves Papegay, Eric Wajnberg *(correspondant)*.

As this was explained in the report written last year, an international collaboration was developed with Israeli scientists located at the Ben-Gurion University of the Negev - published this year [16].Although the currently political situation in Israel renders this scientific connection more difficult, the work developed with these Israeli colleagues was developed further.

Rapidly, we developed a probabilistic model to understand the invasion process in brown widow spiders (*Latrodectus geometricus*) invading populations and habitats of black widow spiders (*Latrodectus indistinctus*). Both species are parasitized by a parasitoids species and it is expected that the parasitoid attack can play a significant role in the ability of the brown widow spiders to invade black widow spiders. A probabilistic model was developed to understand this more formally and to identify situations in which the parasitoid can "help" brown widow spiders to invade black widow spiders. Results obtained look promising and a manuscript is currently under preparation to be submitted in an international journal.

8.3.2 Monte-Carlo simulation models

Participants: Eric Wajnberg.

- During a 8-months sabbatical leave in Brazil (September 1, 2023 till April 30, 2024), invited by the FAPESP (i.e., « Fundação de Amparo à Pesquisa do Estado de São Paulo » ; The São Paulo Research Foundation), in the ESALQ (the biggest agronomic school all over Latin America; belonging to the University of São Paulo), an important Monte Carlo simulation model was developed to understand the spatial and temporal dynamics of the interactions between insect pests (essentially aphids) and their symbiotic bacteria that protect them, at least partially, from attacks by their parasitoids. This topic currently represents an active research area in the literature since the evolutionary mechanisms at play are still not fully understood, and the fact that hosts hosting symbionts can be protected from parasitoid attacks can lead to jeopardize potentially the efficacy of biological control programs using parasitoids as biocontrol agents. The model took into account all the main ingredients on the ecological relationships between hosts, their symbionts and their parasitoids. More specifically, both the vertical (from parents to their progeny) and horizontal (infection to neighboring hosts) transmission of the symbionts were considered, along with the spatial distribution of the aphids in a 2D environment. The cost (in terms of reproductive ability) of hosting symbionts was also considered. This model simulates the interaction between the three protagonists (the hosts, their symbionts and their parasitoids) during 100 generations and also quantifies the efficacy of the parasitoids to control their hosts (biological control efficacy). All computations were done over a computer grid distributed worldwide. The results obtained appeared to be interesting and quite innovative. The dynamics of the association between hosts and their symbionts was influenced by both the longevity of the parasitoid females and the host spatial aggregation pattern. These effects were never considered in the literature before, and can have important consequences in developing efficient pest control strategy based on parasitoids releases. These results have been published in an international journal [18].

- Another topic developed concerns the fact that pollinating bees are foraging for two types of flowers in their environments. Simple flowers (e.g., with one tubular corolla) can produce nectar and pollen that can be found easily by the bees, but in small quantities. On the other hand, complex flowers (e.g., with several inflorescences), are providing more reward, but the bees need time to learn how to exploit them efficiently. For decades, ecologists are wondering about how these two types of flower can persist in the environment, and are suspecting that the pollinating bees play an important role in this. Through a cooperative work with Israeli colleagues (from the Haifa University in the north of Israel), a detailed Monte Carlo model was developed. The goal was to simulate the bees foraging behavior in an environment in which the two types of flower can be found, over several generations, in order to see if these two types of flower can coexist in a steady-state frequency. In all the simulations, with different values of the parameters defining the features of the environment, it was indeed found that the two types of flower can coexist in a stable manner, and the pollinating bees are indeed playing a central role in this. A manuscript has been submitted to an international journal (BMC Ecology and Evolution) and it currently under evaluation.

- A simulation model was developed within the framework of the SPARCBio (São Paulo Advance Research for Biological Control) program, in Piracicaba. The goal was to develop another simulation model to optimize the releasing strategy of the egg parasitoid Trichogramma galloi (Hymenoptera: Trichogrammatidae) against the sugarcane borer Diatraea saccharalis (Lepidoptera: Crambidae). The model produced interesting results demonstrating that the pest population should be more efficiently controlled by increasing the number of weekly releases than by increasing the total number of parasitoids released [14].

- Eric Wajnberg participated to the organization of the 7th International Entomophagous Insects Conference (IEIC7), in Buenos Aires, Argentina, in 2023. Entomophagous insects, which prey on or parasitize other insects, play a pivotal role in ecosystems and are widely utilized as biocontrol agents. All the papers presented during this conference were published in a Special Issue in an international journal in the field of entomology. This Special Issue includes two review articles and nine research papers covering diverse subjects such as ecology, physiology, behavior, genetics, chemical ecology, and biological control, which reflects the diversity of topics presented and discussed during the conference. An introductory publication was produced presenting all these papers [17].

8.3.3 Other research activities developed this year

Participants: Eric Wajnberg.

Another work developed is related to the fact that, globally speaking, the world has become progressively less liberal and democratic in recent years, as can be seen from different metrics publically available. In this respect, in several democracies (e.g., Hungary, Israel, etc.) such decline in democracy had several consequences on ecological research, since it is usually associated with a loss of freedom of speech and free thinking for scientists to conduct independent researches. This is especially true for ecology, conservation, evolution and environmental sciences, disciplines that are progressively in danger. With several colleagues at the international level from Israel, USA and India, a perspective article was written to raise an alarm for the scientific community and the corresponding manuscript has been submitted to an international journal (Conservation Science and Practice). It is now at the last “minor revision” step and should be accepted for publication shortly.

9 Partnerships and cooperations

Participants: Eric Wajnberg.

9.1 International research visitors

9.1.1 Visits of international scientists

Other international visits to the team

Sara Gabaldo

Status PhD

Institution of origin: University of Bologna

Country: Italy

Dates: from September 16 to December 16, 2024

Context of the visit: Collaboration on Underconstrained CDPR

type of mobility: internship

9.1.2 Visits to international teams

Research stays abroad

Eric Wajnberg

Visited institution: University of São Paulo

Country: Brazil

Dates: from September 4, 2023 to May 3, 2024

Context of the visit: Project "Spatial and temporal dynamics of host-symbiont interactions in insects: Toward improving biological control programs against crop pests"

Mobility program: sabbatical

9.2 European initiatives

9.2.1 Other european programs/initiatives

- Hephaistos is part of the euROBIN, the Network of Excellence on AI and robotics that was launched in 2021

9.3 National initiatives

- Hephaistos is part of the AMI EquipEx+ project TIRREX – Technological Infrastructure for Robotics Research of Excellence - dealing with XXL robots.

10 Dissemination

10.1 Promoting scientific activities

10.1.1 Scientific events: organisation

Member of the organizing committees

- Jean-Pierre Merlet is a permanent member of the CableCon conference (International Conference on Cable-Driven Parallel Robots) and chairman of the scientific Committee of the Computational Kinematics workshop.

10.1.2 Journal

Member of the editorial boards

- Eric Wajnberg is Editor-in-Chief of the international journal "BioControl" since September 2006, a member of the Editorial Board of the international journal "Entomologia Experimentalis et Applicata", since 1996, a member of the Editorial Board of the international journal "Applied Entomology and Zoology", since 2003 and a member of the Editorial Board of the international journal "Neotropical Entomology", since 2009.

Reviewer - reviewing activities

- Eric Wajnberg is referee for about 60 international scientific journals. He is reviewing about 20 manuscripts per year.

10.1.3 Editorial activities

- During 2024, Eric Wajnberg did an important editorial work that led to edit and finalize a book that has been released by December 2024 and published by the publisher Wiley-Blackwell [21]. The topic of this volume is on life history evolution, and it addresses traits like body size, timing of maturation, lifespan, ageing, offspring size and number, parental care, sex allocation, social living, dispersal, etc. These different traits are discussed in plants, insects, mammals, and even humans. Also, interactions between predators and their prey, parasites and their hosts, symbionts and their hosts, plants and their herbivores, plants and their pollinators, etc. are also discussed. The book contains 24 chapter, written by a total of 48 authors coming from 17 different countries.

10.1.4 Invited talks

- Jean-Pierre Merlet gave a talk about ethics in experiment to the IEEE Young Professionals during the conference IEEE Humanoids in Nancy and presented his work on solving parametric equations to the PhD students of 3IA.
- Eric Wajnberg has given invited seminars entitled "Stochastic Individual-Based Model (IBM) in parasitoid ecology and Genetic Algorithm" at Universidade Federal de São Carlos, at Universidade de São Paulo in Ribeirao Prato, and at FCAV/UNESP, Jaboticabal in Brazil

10.1.5 Leadership within the scientific community

- Jean-Pierre Merlet is a member of the IFToMM (International Federation for the Promotion of Mechanism and Machine Science) technical Committees on History and on Computational Kinematics. He is a member of the IFToMM Executive Council Publication Advisory Board and an IEEE Fellow.
- Jean-Pierre Merlet has got an Emeritus research director position at INRIA and an emeritus senior chair of 3IA Côte d'Azur since December 2023.
- Jean-Pierre Merlet is a member of the advisory "Conseil des Sages" of GDR Robotique and participates to the GDR working group on "Frugality and sobriety" whose purpose is to reduce the ecological impact of robotics.

10.1.6 Scientific expertise

- Jean-Pierre Merlet is a nominator for the Japan's Prize and is active in the "Robotics in Provence" industrial cluster.
- Yves Papegay is a member of the OpenMath Society, building an extensible standard for representing the semantics of mathematical objects.
- Eric Wajnberg is an appointed member of the Academic Committee of the Hebrew University of Jerusalem, an appointed member of the International Advisory Board of the "International Center for Excellence in Biological Control".

10.1.7 Research administration

- Yves Papegay is the head of local CUMI (Committee of users of the numerical resources and tools).

10.2 Teaching - Supervision - Juries

10.2.1 Teaching

- Jean-Pierre Merlet was one of the animators in the Special Semester on Rigidity and Flexibility 2024 Workshop 5 on "Kinematics Aspects of Robotics", organized by the Radon Institute for Computational and Applied Mathematics (RICAM) of the Austrian Academy of Sciences.

- Clara Thomas has taught 15 hours on parallel robots to Master ISC (M2) at University of Toulon and 64 hours on Mechanics (L2) at Polytech Nice

10.2.2 Supervision

- Jean-Pierre Merlet is supervisor of the PhD of Romain Tissot. Together with Yves Papegay, he is supervising the PhD of Clara Thomas.

10.2.3 Juries

- Eric Wajnberg has been member of a PhD defense committee at the University of Palermo (Trippa D.A., 2024/03/08)

10.3 Popularization

10.3.1 Participation in Live events

- Jean-Pierre Merlet presented twice HEPHAISTOS activities to 3eme interns. He presented the HEPHAISTOS activities on handicap to INRIA general public in several occasions. He gave also two talks about the ecological drawbacks and advantages of electrical mobility (for cars and bikes).
- Clara Thomas and Jean-Pierre Merlet have participated to the Fête de la Science, exhibiting the green robot which has attracted a lot of attention.
- Eric Wajnberg has given eight general public talks in the scope of Science pour Tous 06, about "Pourquoi la sexualité ? Le regard de la biologie", about "Lutter contre les ravageurs de culture - De l'usage des pesticides vers des alternatives plus respectueuses de l'environnement" and about "Les procédures de vote de nos démocraties sont-elles objectives pour connaître la volonté du peuple ? Introduction à la théorie du choix social.".
- In the scope of Inform@thiques.fr, Yves Papegay animated a Summer School on Experimental Mathematics in July in Oxford, for high-school students. He also animated a Summer School on tools for STEAM education, for high-school French and Romanian teachers in Cluj-Napoca and an Autumn School on Data Analysis for French and Romanian high school students in Cluj-Napoca.

11 Scientific production

11.1 Major publications

[1] D. Daney, Y. Papegay and B. Madeline. 'Choosing measurement poses for robot calibration with the local convergence method and Tabu search'. In: *Int. J. of Robotics Research* 24.6 (June 2005), pp. 501–518.

[2] D. Daney, N. Andreff, G. Chabert and Y. Papegay. 'Interval method for calibration of parallel robots: a vision-based experimentation'. In: *Mechanism and Machine Theory* 41.8 (Aug. 2006), pp. 929–944.

[3] J.-P. Merlet. 'Efficient kinematics of a 2-1 and 3-1 CDPR with non-elastic sagging cables'. In: CableCon 2021 - 5th International Conference on Cable-Driven Parallel Robots. Virtual, France, 7th July 2021. DOI: 10.1007/978-3-030-75789-2_1. URL: https://hal.inria.fr/hal-03284195.

[4] J.-P. Merlet. 'Interval Analysis and Reliability in Robotics'. In: *International Journal of Reliability and Safety* 3 (2009), pp. 104–130. URL: http://hal.archives-ouvertes.fr/inria-00001152/en/ (cit. on p. 6).

[5] J.-P. Merlet. 'Maximal cable tensions of a N-1 cable-driven parallel robot with elastic or ideal cables'. In: CableCon 2021 - 5th International Conference on Cable-Driven Parallel Robots. Virtual, France, 7th July 2021. DOI: 10.1007/978-3-030-75789-2_7. URL: https://hal.inria.fr/hal-03284191.

[6] J.-P. Merlet. 'Mixing AI and deterministic methods for the design of a transfer system for frail people'. In: Sophia IAsummit. Sophia-Antipolis, France, 17th Nov. 2021. URL: https://hal.inria.fr/hal-03436170.

[7] J.-P. Merlet. 'The kinematics of cable-driven parallel robots with sagging cables: preliminary results'. In: ICRA 2015 - IEEE International Conference on Robotics and Automation. Seattle, United States, 2015, pp. 1593–1598. DOI: 10.1109/ICRA.2015.7139401. URL: https://hal.archives-ouvertes.fr/hal-01259258.

[8] J.-P. Merlet. 'Using interval analysis in robotics problems'. In: SCAN. Tokyo, Japan, Sept. 2018. URL: https://hal.archives-ouvertes.fr/hal-01965228.

[9] J.-P. Merlet. *Parallel robots, 2nd Edition*. Springer, 2005 (cit. on p. 7).

[10] N. Nevejans, O. Pourtallier, S. Icart and J.-P. Merlet. 'Les avancées en robotique d'assistance à la personne sous le prisme du droit et de l'éthique'. In: *Revue générale de droit médicale* (Dec. 2017). URL: https://hal.inria.fr/hal-01665077 (cit. on p. 4).

[11] Y. Papegay. 'De la modélisation littérale à la simulation certifiée'. Habilitation à Diriger des Recherches. Nice, France: Université de Nice Sophia-Antipolis, June 2012. URL: http://tel.archives-ouvertes.fr/tel-00787230 (cit. on p. 7).

[12] Y. Papegay. 'From Modeling to Simulation with Symbolic Computation: An Application to Design and Performance Analysis of Complex Optical Devices'. In: *Proceedings of the Second Workshop on Computer Algebra in Scientific Computing*. Munich: Springer Verlag, June 1999.

[13] G. Trombettoni. 'A Polynomial Time Local Propagation Algorithm for General Dataflow Constraint Problems'. In: *Proc. Constraint Programming CP'98, LNCS 1520 (Springer Verlag)*. 1998, pp. 432–446 (cit. on p. 6).

11.2 Publications of the year

International journals

[14] A. Gomes Garcia, E. Wajnberg and J. R. P. Parra. 'Optimizing the releasing strategy used for the biological control of the sugarcane borer Diatraea saccharalis by Trichogramma galloi with computer modeling and simulation'. In: *Scientific Reports* 14.1 (25th Apr. 2024), p. 9535. DOI: 10.1038/s41598-024-60146-y. URL: https://inria.hal.science/hal-04566586 (cit. on p. 15).

[15] J.-P. Merlet. 'Mixing neural networks, continuation and symbolic computation to solve parametric systems of non linear equations'. In: *Neural Networks* 176 (2024), p. 106316. URL: https://inria.hal.science/hal-04609234 (cit. on p. 10).

[16] M. Segoli, Y. Papegay, T. Rozenberg and E. Wajnberg. 'Why do predators attack parasitized prey ? Insights from a probabilistic model and a literature survey'. In: *Behavioural Processes* 216 (Mar. 2024), p. 105002. DOI: 10.1016/j.beproc.2024.105002. URL: https://inria.hal.science/hal-04459377 (cit. on p. 14).

[17] D. Segura, M. F. Cingolani, E. Wajnberg and L. Beukeboom. 'Entomophagous insects: Predators and parasitoids that shape insect communities and offer valuable tools for insect pest management'. In: *Entomologia Experimentalis et Applicata* 172.6 (3rd Apr. 2024), pp. 455–459. DOI: 10.1111/eea.13446. URL: https://inria.hal.science/hal-04566733 (cit. on p. 16).

[18] E. Wajnberg and F. Cônsoli. 'Dynamics of Insects and Their Facultative Defensive Endosymbiotic Bacteria: A Simulation Model'. In: *Ecology and Evolution* 14.12 (3rd Dec. 2024). DOI: 10.1002/ece3.70676. URL: https://inria.hal.science/hal-04816246 (cit. on p. 15).

International peer-reviewed conferences

[19] J.-P. Merlet. 'The inverse kinematics of cable-driven parallel robot with more than 6 sagging cables Part 1: from ideal to sagging cables'. In: *ARK*. ARK 2024 - 19th International Symposium on advances in robot kinematics. Ljulbjana, Slovenia: Springer, 30th June 2024. URL: https://inria.hal.science/hal-04609258 (cit. on p. 9).

[20] J.-P. Merlet. 'The inverse kinematics of cable-driven parallel robot with more than 6 sagging cables Part 2: using neural networks'. In: *ARK*. ARK 2024 - 19th International Symposium on advances in robot kinematics. Ljlubljana, Slovenia: Springer, 30th June 2024. URL: https://inria.hal.science/hal-04609264 (cit. on p. 9).

Scientific book chapters

[21] E. Wajnberg. 'Monte Carlo Simulations to Model the Behaviour of Agricultural Pests and Their Natural Enemies'. In: *Modelling Insect Populations in Agricultural Landscapes*. Vol. 8. Entomology in Focus. Springer International Publishing, 1st Feb. 2024, pp. 29–47. DOI: 10.1007/978-3-031-43098-5_3. URL: https://inria.hal.science/hal-04440120 (cit. on p. 18).

Doctoral dissertations and habilitation theses

[22] R. Tissot. 'Use of AI for the analysis of a cable-driven parallel robot designed to assist vulnerable individuals'. Universite Cote d'Azur, 13th Dec. 2024. URL: https://hal.science/tel-04926142 (cit. on p. 10).

Scientific popularization

[23] J.-P. Merlet. 'Une histoire de la robotique d'aujourd'hui'. In: *Interstices* (28th Nov. 2024). URL: https://inria.hal.science/hal-04848072.