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ACTIVITY REPORT

Project-Team AUCTUS

Robots for Humans at work

DOMAIN

Perception, Cognition and Interaction

THEME

Robotics and Smart environments

Inria

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Project-Team AUCTUS

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2 Overall objectives

The project of the Auctus team is to design the collaborative robotics cells of the future.

The robotics community still tends to separate Human-Robot interaction's cognitive (HRI) and physical (pHRI). One of the main challenges is to characterize the task and biomechanical, physiological and cognitive capabilities of humans in the form of physical constraints or objectives for the design of cobotized workstations. This design must be understood in a large sense: the choice of the robots' architecture (cobot, exoskeleton, human-robot interface, etc.), the dimensional design (human/robot workspace, trajectory calculation, etc.), the coupling mode (comanipulation, teleoperation, etc.) and the control strategy. The approach then requires the contributions of the human and social sciences to be considered in the same way as those of exact sciences. The topics considered are broad, ranging from cognitive sciences, ergonomics, human factors, biomechanics and robotics.

The first challenge is to evaluate the hardship at work, the well-being of the operators and, further upstream, their cognitive state which impacts their sensorimotor strategy while performing a task. In the industry, the ergonomic analysis of the task is carried out by an ergonomist based on direct but often ad hoc observations. However, the context is changing: the digitization of factories, through the installation of on-site sensors, allows longitudinal observation of machines and humans. The available information can thus allow us to rethink how the evaluation of activities is carried out. Currently, an emerging subdomain, named *ergonomic robotics*, adapts available ergonomic criteria (RULA, REBA, etc.) to the evaluation of robotic cells. However, such criteria are related to the (quasi-static) posture of the operator, which limits the understanding of human motor strategies over a long period. Similarly, muskuloskeletal analyses may tend to see humans as high-performance machines to be optimized. This can make sense for a top-level athlete, but repeating actions in the industry over a day, months or years of work means that a temporary change of posture, possibly poorly rated according to usual ergonomic criteria, could be a good long-term strategy. These questions directly link motor and cognitive aspects that can be reflected in particular strategies such as fatigue or expertise (manual and cognitive). We aim to creat musculoskeletal metrics through extensive modeling of the human at work. This approach has not been widely explored in robotics but it could determine the right criteria to adapt to the behavior of a cobot.

The second challenge is to define a methodology to link the analysis of the task and the induced human movements to the robot design. Several of our industrial projects have shown that there is a significant conceptual distance between the ergonomist, an expert in task analysis and psychology, and the roboticist, an expert in mechanics, control and computer science, which makes it very difficult to analyze the needs and define the specifications of the technical solution. To fill these methodological gaps, it is necessary to better define the notion of tasks in the context of a human/robot coupling, based on case studies. We also have to establish a typology of human/robot interaction by taking into account the different physical and cognitive constraints, in a very detailed fashion, and their potential psychological, organizational or ethical impacts.

The third challenge addresses the need to think about the control laws of collaborative robots in terms of human/robot coupling. The effectiveness of this coupling requires an ability to predict future human actions. This prediction should make the interaction more intuitive, but also aims at optimizing the robot assistive behavior from the point of view of "slow" phenomena, such as fatigue. The major challenge is, therefore, to move from reactive to anticipatory control laws, by integrating a human prediction model, both in terms of movement strategies and decision strategies. Beyond the great computational complexity of predictive approaches, obtaining prediction models is an ambitious challenge. It is indeed necessary to learn models that are quite complex, due to the physical realities they can account for, and quite simple from a computational point of view.

3 Research program

3.1 Analysis and modeling of human behavior

3.1.1 Scientific Context

The purpose of this axis is to provide metrics to assess human behavior. Our human study specifically focuses on industrial operators. We assume the following working hypotheses: the operator's task and environmental conditions are known and circumscribed; the operator is trained in the task, production tools and safety instructions; the task is repeated with more or less frequent intervals. We aim to analyze the following:

- the physical and cognitive fragility of operators to meet assistance needs;
- cognitive biases and physical constraints leading to a loss of the operator safety;
- ergonomics, performance and acceptance of the production tool.

In the industrial context, these questions are tackled through the fields of work ergonomics and cognitive sciences. Four main axes are typically addressed: physiological/biomechanical, cognitive, psychological and sociological studies. We particularly focus on the biomechanical, cognitive and psychological aspects, as described by the ANACT [28, 31]. The aim is to translate these factors into metrics, optimality criteria or constraints to better analyze, design and control the collaborative robots.

A review of ergonomic workstation evaluation helps in positioning our desired contributions in robotics. Ergonomists evaluate the gesture through the observation of the workstations and, generally, through questionnaires. This requires long periods of field observation, followed by analyses based on ergonomic grids (e.g. RULA [43], REBA [35], LUBA [39], OWAS [38], ROSA [56],...). Until then, the use of more complex measurement systems was reserved for laboratories, particularly in biomechanical studies. The advent of cost-effective and minimally intrusive motion capture sensors (Inertial Measurement Units, RGB-D cameras), coupled with advancements in computer vision algorithms, now enables on-site data collection to assess workers' gestures, postures, movements, and physiological states. Some of these systems can be permanently integrated into production lines without disrupting workflow, while simultaneously evaluating worker well-being through biomechanical and physiological metrics. This facilitates longitudinal motion capture studies, similar to the evolution of maintenance practices from reactive to predictive.

Ergonomic robotics has recently taken an interest in this new evaluation paradigm to adapt the robot behavior to reduce ergonomic risks. This ergonomic adaptation complements the conventional approaches that only consider the performance of the action produced by the human in interaction with the robot. However, ergonomic criteria are usually based on the principle that the comfort positions are distant from the human joint limits. These notations are compatible with an observation of the human operator through the eye of the ergonomist. In practice, such evaluations are inaccurate and subjective [59]. Moreover, they only consider quasi-static human positions, without taking into account the evolution of the person's physical, physiological and psychological state. We aim to extend this approach to more reliable and comprehensive ergonomic metrics with musculoskeletal, fatigue, metabolic consumption modelling. The repetition of gestures, and the solicitation of muscles and joints, are questions that must complete these analyses. A method used by ergonomists to limit biomechanical exposures is to increase variations in motor stress by rotating tasks [57]. However, this type of extrinsic method is not always suitable in the industrial context [42] where we place our research efforts.

Through these human analyses, the Auctus team aims to revise the use of collaborative robots in the workplace to vary the operator's environment and encourage more appropriate motor strategies. Biomechanical studies of the intrinsic variability of the motor system allowed by the joint redundancy of the human body should result in the alternation of postures, movements and muscle activity observed in the individual to perform a requested task [57]. This variation leads to differences between the motor coordination used by each operator, and conveys the notion of motor strategy [36]. We aim to provide exhaustive studies of motor strategies in industrial setups.

The cognitive dimension of ergonomics must also be addressed in our approach to reduce the mental workload and foster the wellness of the worker. We believe that known sensorimotor strategies can be a physically quantifiable reflection of the operator's cognitive state. For example, human motion measurements can be used to predict fatigue [54] and, therefore, adjust the robot's assistance. A key challenge here is to better analyze human manual expertise (dexterous and cognitive) to adapt the human-robot interaction. The expertise embodies the operators' decision-making process while perceiving, understanding, and anticipating their gestures to preserve their safety, comfort, and performance in the task. We aim to adapt and refine known human cognitive models (multisensory perception [33], situation awareness [32]) to infer the influence of the task context and environment on operator behavior.

3.1.2 Methodology

How can we observe, understand and quantify human sensorimotor and cognitive strategies to better design and control the behavior of the cobotic assistant?

When we study systems of equations (kinematic, static, dynamic, musculoskeletal, etc.) to model human behavior, several problems appear and explain our methodological choices:

- the large dimension of the problems to be considered, due to the human body complexity (eg. joint, muscle redundancy);
- the distribution of anthropometries, force capacities, and fatigue resistance among workers, for example, size, the muscle mass, the possible geometric configurations on a workstation (set of possible trajectories, postures, and placements of the operator), and the forces needed to be produce to execute a task;
- the uncertainties in the measurement and the model approximations.

The idea is to start with a description of redundant workspaces (geometric, static, dynamic...). We use set-theory approaches, based on interval analysis [58], [48], which meet the variability requirement and cope with model and measurement uncertainties. Another advantage of such techniques is that they allow the results to be certified, which is essential to address safety issues. Some members of the team have already achieved success in mechanical design for performance certification and robot design [45]. By extending these set-theory approaches to our problem, a mapping of ergonomic, efficient, and safe movements can be obtained, in which we project the operators' motor strategies. Biomechanical, ergonomic, and cognitive metrics can, then, be defined and evaluated to quantify the human behavior in specific work situations.

It is therefore necessary to:

- model human capabilities, both at the musculoskeletal and the perceptive/cognitive levels, to allow for global, yet detailed, analyses as well as efficient integration of such knowledge in the control of the collaborative robots.
- contribute to accurate representations of the shoulder joint involved in most cobotic interactions and worker efforts. Its complex range of motion and the numerous muscles involved make proper shoulder modeling a significant challenge for musculoskeletal (MSK) models [10].
- propose new ergonomic, biomechanical, robotic, and cognitive indices that will link different types of performances while taking into account the influence of fatigue, stress, level of expertise, etc.;
- divide the task and the gesture into homogeneous phases: this process is complex and depends on the type of studied index and the techniques being used. We are exploring several methods: inverse optimal control, learning methods, techniques from signal processing;
- develop interval extensions of the proposed indices. The indices are not necessarily the result of a direct model, and algorithms must be developed or adapted to compute them (calculation of manipulability, Uncontrolled Manifold, etc.);
- Aggregate proposals into a dedicated interval-analysis library for human behavior studies (use of and contribution to the existing ALIAS-Inria and the open-source IBEX library).

The major contribution of the methodology is to embrace in the same model the measurement uncertainties (important for on-site use of measurement equipment), the variability of tasks and trajectories (proper to dexterous industrial operations), and the physiological characteristics of the operators (critical adaptability to every individual). The originality of the approach is to combine biomechanical, ergonomic and cognitive metrics with the usual performance indices to build a comprehensive and objective analysis of human behavior.

Other avenues of research are being explored, particularly around the inverse optimal control [49], to project human movements based on the performance or ergonomic indices. Such a projection would offer new interpretations and enhance the analysis of human behaviors.

Finally, the development of a population-scale musculoskeletal model database and the application of anthropometry-robust optimal control represents a new aera of research that the team will explore by 2025. This approach would further explore the inherent variability within human workforces. By constructing a diverse virtual population through statistical and biomechanical principles, we will be able to leverage predictive simulation to identify broadly applicable movement strategies and minimize potential strain across a spectrum of worker morphologies and capabilities. This dual approach moves beyond traditional, one-size-fits-all ergonomic assessments, enabling the development of personalized or, at minimum, broadly robust recommendations for safer and more efficient work practices.

3.2 Operator/robot coupling

This research axis is at the frontier between humans and robots and focuses on optimal methods to couple these two entities to perform joint activities. This raises questions that are directly related to human models and abilities (axis 1) and robot control (axis 3). Two main concerns must be addressed to form an effective human-robot dyad.

3.2.1 Human-Robot interaction

The first step to couple the operator and cobot together at work is to provide interaction modalities through which the agents can communicate and coordinate. The interaction can be direct, where the robot and operator act together in the same shared environment, or the operator can remotely perform the task with the robot through a teleoperation system (which reflects the remote interaction and potentially corrects for punctual weaknesses). The level and type of human-robot interactions are chosen with respect to the task, the context, or other human factors. The challenge is, then, to predict the joint human-robot behavior and capabilities for each interaction situation and collaborative context.

The formal computation of joint human-robot capabilities can be given thanks to the models and evaluation indices presented in Axis 1. We can focus on quantifying how the interaction with the robot will impact the human sensorimotor strategy (changes in the posture, positions, forces, etc., induced by the robot) and recomputing metrics such as human fatigue and motor variability[53] and the Mover project. We can further use the biomechanical and robotic models to consider a unified operator-robot entity and to compute their joint abilities (e.g. common human-robot force capabilities [55]).

Developing human cognitive and sensorimotor models to account for the effect of the human-robot interaction could provide a valuable tool to evaluate cobotic systems and collaborative works. However, the accuracy of these models must be addressed. We wish to understand how the robot influences the operator's work, and thus how his mental model of the task evolves according to the interactions with the robot. The challenge is, then, to predict the behavior of the operator that takes into account his cognition in the interaction situations. Preliminary literature results have shown that key cognitive mechanisms in human teaming may transfer to human-robot collaboration, such as joint human-robot action representation [29] or coordination mechanisms [47]. However, the situation awareness of the operator is modified by the interaction with the robot [52]. Developing a joint mental model that accurately captures the human-robot interaction can later guide the design of relevant interaction modalities to improve the team's understanding [2].

3.2.2 Cobot adaptive assistance

Taking into account the coupling between the operator and the robot at the control level is also central to the team's objectives. We wish to demonstrate how a collaborative robot can be used to mediate between a control objective that optimizes task performances, safety and comfort (what we consider as the *expertise trinity*), on one hand, and the action model of the human interacting with the robot (the inferred human intent), on the other hand. Such an arbitration in the control law adapts the robot's assistive behavior to better collaborate with the operator. This shared-autonomy concept is the focus of part of our research. It can range from a discrete task allocation between the agents to an effectively shared task [46].

We are strongly confident that the notion of expertise is central to adjusting the cobot behavior. The robot controller is designed to increase the level of expertise in the operator/robot team: it optimizes the human-centered metrics (safety criteria, biomechanical and cognitive comfort, etc.) and provides a gain in performances (joint human-robot capabilities). But it also aims at preserving the operator's particular expertise and know-how at the center of the activity. Manual expertise of highly skilled operators needs to be analyzed respectively on its dynamic aspects and on the ability to synchronize with other operators in the environment. Understanding better the expertise is envisioned as a way to alleviate the operators of repetitive and easy operations while maintaining their ability to perform expert gestures based on the complexity of the task.

Furthermore, this research axis raises the question of the modification of the work induced by collaborative robots for expert operators. While the overall goal is to make use of robots to punctually or continuously improve the work conditions of these operators (and not to replace them), the presence of these robots necessarily impacts the work referential and thus the expertise itself. One of the central questions, yet to be tackled, relates to the original and core part of the expertise that should remain unchanged. The proposed modeling of the operator/robot coupling and interaction is the first avenue to predict possible changes in the expertise. It can be input to the controller to constraint the robot to let the operator make the expert decisions naturally.

3.3 Design of cobotic systems

3.3.1 Architectural design

Is it necessary to cobotize, robotize or assist the human being? Which mechanical architecture meets the task challenges (a serial cobot, a specific mechanism, an exoskeleton)? What type of interaction (H/R cohabitation, comanipulation, teleoperation)? These questions are the first requests from our industrial partners. For the moment, we have few comprehensive methodological answers to these requests. Choosing a collaborative robot architecture is a difficult problem [40]. It becomes even more complex when the architectural design is approached from concurrent cognitive ergonomic, biomechanical and robotic perspectives. There are major methodological and conceptual differences in these areas. It is, therefore, necessary to bridge these representational gaps and to propose a global and generic approach that takes into consideration the expectations of the robotician to model and formalize the general properties of a cobotic system as well as those of the ergonomist to define the expectations in terms of an assistance tool.

To do this, we propose a user-centered design approach, with a particular focus on human-system interactions. From a methodological point of view, this requires to develop a structured experimental approach. It aims at characterizing the task to be carried out ("system" analysis) but also at capturing the physical markers of its realization (required movements and efforts, ergonomic stress, etc.). This specification must be done through the prism of a systematic study of the exchanged information (type and modality) needed by humans to perform the considered task. Based on these analyses, the main challenge is to define a decision support tool for the choice of the robotic architecture and the specifications of the role assigned to the robot and the operator as well as their interactions.

The evolution of the chosen methodology is for the moment empirical, based on the user cases regularly treated in the team (see sections on contracts and partnerships).

The process can be summarized through the following steps:

- identify expert or difficult jobs on industrial sites. This is done through visits and exchanges with our partners (manager, production manager, ergonomist...);
- select some challenging use cases to be studied and, then, observe the operator in its ecological environment. Our motion capture tools allow us to produce a force-motion analysis, based on

previously defined ergonomic criteria, and a physical evaluation of the task in terms of expected performances, from both experiments and simulations. In parallel, an evaluation of the operator's expertise and cognitive strategy is throught questionnaires;

- synthesize these observatory results into design requirements to deduce: the robotic architectures to be initiated, the key points of human-robot interaction to be developed, and the difficulties in terms of human factors to be taken into account.

The different human and task analyses take advantage of the expertise available within the AUCTUS team. The team has already worked on the currently dominant approach: the use of human models to design the cobotic cell through virtual tools [3]. We would like to gradually introduce the additional evaluation criteria presented above. However, the very large dimensions of the treated problems (modeling of the body's degrees of freedom and the constraints applied to it) makes it difficult to carry out a certified analysis. We choose to go through the calculation of the human workspace and performances, which is not yet done in this field. The idea here is to apply set theory approaches, using interval analysis as already discussed in section 3.1.2. The goal is, then, to extend the human constraints to intervals, which integrate the model variability, and to play them in virtual reality during simulations of the tasks. This would allow the operator to check his trajectories and scenarios not only for a single case study but also for sets of cases. For example, it can be verified that, regardless of the bounded sets of simulated operator physiological capabilities, the physical constraints of a simulated trajectory are not violated. Therefore, the assisted design tools certify cases of use as a whole. Moreover, the intersection between the human and robot workspaces/capabilities provides the necessary constraints to certify the feasibility of a task in the interaction situation. Overall, integrating human and task-related physical constraints in the design process brings to better cobotic systems. In the future, we will similarly develop tools to include human cognitive markers in the design approach.

This research line merges the contributions of the other axes, from the analysis of the human behavior and capabilities in its environment for an identified task, the prediction of the effects of the interaction/coupling strategy with the robot, to the choice of a mechanical architecture from the resulting design constraints. The proposed task-oriented and human-centered methodology is perfectly integrated into an Appropriate Design approach. It can be used for the dimensional design and optimization of robots, again based on interval analysis. The challenges are the change of scale in models that symbiotically consider the human-robot pair, the uncertain, flexible and uncontrollable nature of human behavior, and the many evaluation indices needed to describe them.

It is worth noting that we aim to develop a global mechatronic design approach, which would build upon the design constraints to specify the robot hardware and controller at once. The chosen set-theory computational methodology is particularly appropriate to meet this objective since the interval-based representation of the design constraints can be directly and equally used to set the control constraints.

3.3.2 Control design

The control laws of collaborative robots from the major robot manufacturers differ little or not at all from the existing control laws in the field of conventional industrial robotics. Security is managed a posteriori, as an exception, by a security PLC / PC. It is therefore not an intrinsic property of the controller. This strongly restricts possible physical interactions [1] and leads to suboptimal operation of the robotic system. It is difficult in this context to envision tangible human-robot collaboration. Collaborative operation requires, in this case, a control calculation that integrates safety and ergonomics as a priori constraints.

The control of truly collaborative robots in an industrial context is, from our point of view, underpinned by two main issues. The first one is related to the macroscopic adaptation of the robot's behavior according to the phases of the production process. The second one is related to the fine adaptation of the degree and/or nature of the robot's assistance according to the ergonomic state of the operator. If this second problem is part of a historical dynamics in robotics that consists in placing safety constraints, particularly those related to the presence of a human being, at the heart of the control problem [34] [44, 37], it is not approached from the more subtle point of view of ergonomics where the objective cannot be translated only in terms of human life or death, but rather in terms of long-term respect for their physical

[1] In the ISO TS 15066 technical specification on collaborative robotics, human-robot physical interaction is allowed but perceived as a situation to be avoided.

and mental integrity. Thus, the simple and progressive adoption by a human operator of the collaborative robot intended to assist him in his gesture requires a self-adaptation in the time of the command. This self-adaptation is a fairly new subject in the literature [50, 51].

At the macroscopic level, the task plan to be performed for a given industrial operation can be represented by a finite-state machine. To avoid increasing the human's cognitive load by explicitly asking him to manage transitions for the robot, we propose to develop a decision algorithm that would ensure discrete transitions from one task (and the associated assistance mode) to another based on an online estimate of the current state of the human-robot couple. The associated scientific challenge is to establish a link between the robot's involvement and a given working situation. We propose an incremental approach to learn this complex relationship. Its first stage will consist of identifying the general and relevant control variables to conduct this learning in an efficient and reusable way, regardless of the particular calculation method of the control action. Then, physically realistic simulations and real-world experiments will be used to feed this learning process.

To handle mode transitions, we propose to explore the richness of the multi-tasking control formalism under constraints [41]. It would ensure a continuous transition from one control mode to another while guaranteeing compliance with a certain number of robot control constraints. Some of these constraints convey the ergonomic specifications and are dependent on the state of the robot and of the human operator, which, by nature, is difficult to predict accurately. We propose, again, to exploit the interval-analysis paradigm to efficiently formulate ergonomic constraints robust to the various existing uncertainties.

Purely discrete or reactive adaptation of the control law would make no sense given the slow dynamics of certain physiological phenomena such as fatigue. Thus, we propose to formulate the control problem as a predictive problem where the impact of the control decision at a time t is anticipated at different time horizons. This requires a prediction of human movement and knowledge of the motor variability strategies it employs. This prediction is possible based on the supervision at all times of the operational objectives (task in progress) in the short term. However, it requires the use of a virtual human model and possibly a dynamic simulation to quantify the impact of these potential movements in terms of performances, including ergonomics. It is impractical to use a predictive command with simulation in the loop with an advanced virtual manikin model. We, therefore, suggest adapting the prediction horizon and the complexity of the corresponding model to guarantee a reasonable computational complexity.

4 Application domains

4.1 Factory 4.0

The 4th industrial revolution (factory 4.0) is characterized by the integration of digital technologies into the production process, to meet the challenge of customizing services and products. This agility requires making manufacturing and maintenance lines flexible and versatile. This adaptation capacity is a characteristic of the human being, which puts him at the center of the production apparatus. However, this can no longer be done at the expense of the human operators' health and well-being. How can we reconcile the enhancement of our manual and analytical expertise, the ever-desired increase in productivity and manufacturing quality, while reducing the hardship at work? Collaborative robotics, which we are seeking to build, is one of the key solutions to meet these societal challenges. By assisting humans while performing dangerous and painful tasks, the collaborative robot complements and helps them in their phases of physical and cognitive fragility.

More generally, we are interested in workstation cobotization, in the manufacturing and assembly industries but also the construction and craft industries. The application areas are related to regional needs in aeronautics, maintenance, water and waste treatment. In most of these cases, it is possible to define the tasks and to evaluate the stakes and added value of our work.

5 Social and environmental responsibility

The scientific positioning of Auctus has an explicit social objective: assisting industrial workers to improve their working conditions through the appropriate limitations of physical solicitations and the improvement of their cognitive comfort. This has a direct societal impact on the health of the population and regarding the preservation of industrial skills and expertise in the local and national industrial ecosystem.

From an environmental point of view, the research goals of Auctus do not explicitly aim at improving the human footprint on the planet or at better understanding environmental related issues and processes. Yet, some of our projects can have a direct impact on these issues. This impact is for example directly related to the application context in the case of our collaboration in the domain of remote operation of technical skills with the Farm3 company. Indeed, this company aims at producing plants locally, with a reduced physical footprint while minimizing water consumption. We also envision a less direct but more fundamental impact of our work in the control, mechatronics and mechanical architecture domains where we aim at exploiting at best robot capabilities. In the long term, the impact of this work should lead to a reduction of the size of robots and of the amount of energy they consume to achieve a given task. This is clearly in line with the general objective of saving energy as well as the natural resources.

5.1 Involvement in working groups

- Margot Vulliez is member of the Committee on Gender Equality and Equal Opportunities (GT Parité-Egalité) for the Inria Bordeaux research center, since January 2024.
- Vincent Padois and Margot Vulliez participate in the activities of the priority action AP1 on Robotics and Sobriety of the GDR Robotique.

6 Highlights of the year

- The Auctus team has been awarded two Défi Transfert projects from the France 2030 ANR program. This program aims at accelerating the transfer and valorization of research results from research laboratory towards innovative French companies. The first project, **Grip4All**, led by David Daney, aims at robotic palletization of heterogeneous products without prior scheduling and which could bring a competitive advantage in the industrial logistic chain. The second project, **Extender**, led by Sorbonne Université, aims at the robust, safe and intuitive control for a manipulator arm that can be adapted to the changing needs of people with disabilities. These two projects, officially started in December 2024 and will lead to the recruitment of four research engineers and the development of proof-of-concept mock-ups to ease technology readiness demonstration and transfer to the industrial partners of each project.
- The **SHAARE associate team** has started this year between the **IRiS lab at KAIST** (co-investigator Jee-Hwan Ryu) and the Auctus team. SHAARE aims at coupling our complementary methodological approaches in haptic shared control. Our first collaborative work focuses on the online deformation of haptic guidance trajectory based on the user interaction during the task. It is principally carried out by Alexis Boulay (PhD Inria), in collaboration with Kwang-Hyun Lee (Postdoc KAIST), and is the result of his research visit at the IRiS lab, Daejeon South Korea, from September to November 2024.
- The Auctus team was involved in two major public events aiming at disseminating knowledge towards a large audience. The first one was held at Bordeaux City Hall within the framework of the **Journées RobNA – Robotique en Nouvelle Aquitaine**, co-organized by the Regional Research Network on Robotics. The second one was held at **Humanoids 2024**, in Nancy. Both event were really succesful and received a massive positive feedback from the public.

7 New software, platforms, open data

7.1 New software

7.1.1 Qontrol

Name: Quadratic Optimization coNTROL

Keywords: Robotics, Control, Optimisation

Scientific Description: Generic expression of a robot control problem using constrained optimization in a dynamic environment, applicable to robots that can be controlled in terms of torque, speed or position.

Functional Description: Qontrol is a tool for the generic formulation of robotic control problems in the form of constrained optimization problems. It is initially intended for fixed-base polyarticulated robots. It allows to easily create tasks and constraints in the control law.

News of the Year: Declaration to the Program protection office. Appears in "transfert challenge" kind of project (awaiting for finding) Appears in a european project (awaiting for finding)

URL: https://auctus-team.gitlabpages.inria.fr/components/control/qontrol/index.html

Contact: Lucas Joseph

Participants: Lucas Joseph, Vincent Padois

7.1.2 ROS Haptic Teleop

Keywords: Telerobotics, Haptic

Functional Description: ros_haptic_teleop defines the following parameters : scaling factor and transformation matrix between two robot and haptic frames, homing poses for both robots, and control gains used for homing of the robots or to maintain the haptic device pose. An integrated RViz plugin handles the different modes of operation (teleop, homing, maintain) from buttons of the visual interface. The package subscribes to the pose and velocity topics of the robot and the haptic device. It transforms these references (scaling and rotation) in the other robot's space, and publishes the transformed quantities (scale_pose and scale_velocity). These transformed pose/velocity are input to the robot motion controller (external). It also subscribes to the external force sensed by the robot and publishes the transformed value to generate a direct haptic feedback on the interface (external force controller). It interfaces with external haptic controllers, by subscribing to their command topics, such as the guiding force (active constraint) or the shared pose and velocity (blending), and by integrating them to the robots' control inputs. These external references are enabled through activation parameters (enable_ac and enable_blending).

URL: https://gitlab.inria.fr/auctus-team/people/alexisboulay/teleoperation_ros/ros_haptic_teleop

Contact: Alexis Boulay

Participants: Alexis Boulay, Margot Vulliez, Lucas Joseph

7.1.3 Chai3D Haptic Driver

Keywords: Telerobotics, Haptic

Functional Description: This driver is based on the chai3d library. It handles any haptic device which has been defined in chai3d/src/devices. Falcon device of Novint and Omega/Sigma/Delta devices of Force Dimension are available by default. Device specifications such as the maximal force, stiffness, and damping, are made accessible as ros messages. This driver provides cyclical exchanges with the opened haptic device. It publishes pose and velocity data on ros topics. It subscribes to the desired force topic to provide the haptic feedback through the interface. It also manages the device's gripper/buttons through dedicated ros topics.

URL: https://gitlab.inria.fr/auctus-team/people/margotvulliez/chai3d_haptic_driver

Contact: Margot Vulliez

Participants: Margot Vulliez, Alexis Boulay

7.1.4 Active Constraint

Keywords: Haptic guidance, Haptic, Telerobotics

Scientific Description: The implementation of an active constraint or virtual guide in a teleoperation context with a haptic interface aims to encourage operators to follow a desired behaviour while allowing a certain freedom of action. This package also includes the integration of a generic formula enabling a continuous transition between the different types of generic guides (potential fields, spring-damper and guide tube).

Functional Description: active_constraint defines the following parameters: stiffness and damping factors for 3 different types of guidance (potential field, spring-damper and guide tube), as well as threshold distances and parameters enabling guidance to be generated using a generic approach. The integration of a RVIZ plugin means that it is possible to change on the fly between each guide and to modify the above-mentioned parameters. The package subscribes to the position and velocity topics of the robot and the scaled haptic interface in the robot workspace. These positions and speeds are used to generate a guidance force which is sent to the communication hub linked to the haptic interface. This package also allows the definition of obstacles and targets required to generate guidance, the relative poses are then published.

URL: https://gitlab.inria.fr/auctus-team/people/alexisboulay/teleoperation_ros/active_constraint

Contact: Alexis Boulay

Participants: Alexis Boulay, Margot Vulliez, David Daney

7.1.5 MPC based shared control

Name: Model Predictive control based Shared Control

Keywords: Robotics, Telerobotics, Optimal control, Shared control, Collaborative robotics

Functional Description: This software is designed for Human-Robot Interaction (HRI) applications, enabling Smooth integration of human input with an existing assistance system. The controller dynamically blends both inputs, ensuring that human commands are refined while preserving the overall task objectives. By enforcing workspace constraints and respecting the robot's physical capabilities, the system guarantees safe and feasible motion execution. Additionally, it actively mitigates unwanted oscillations caused by abrupt or jerky human inputs, resulting in smoother and more stable robot behavior.

URL: https://gitlab.inria.fr/auctus-team/people/eliojabbour/mpcontroller.git

Contact: Elio Jabbour

7.1.6 mpc_tutorial

Keywords: Robotics, Optimal control

Functional Description: This repository provides a set of python scripts solving on toy optimal control problems (simple pendulum, cartpole, etc.). The goal is to familiarize with the core concepts and methods from Optimal Control theory (continous and discrete time).

URL: https://github.com/skleff1994/mpc_tutorial

Contact: Sebastien Kleff

7.1.7 force_feedback_mpc

Keywords: Robotics, Control, Optimization

Functional Description: This library is basically an extension of the Crocoddyl optimal control library: it implements custom action models in C++ allowing to quickly prototype MPC schemes with force feedback.

URL: https://github.com/machines-in-motion/force_feedback_mpc/tree/constraints

Contact: Sebastien Kleff

7.1.8 POP-ART

Name: Performant Optimization Problems for Advanced Robot Trajectories

Keywords: Robotics, Motion control, Trajectory Generation, Optimization

Functional Description: A set of methods dedicated to advanced robot motion generation through efficient constrained optimization formulation, coded and examplified in Python. More precisely a ROS workspace for the QP-based control of robots using Pinocchio and including : - a simple QP based controllers expressed at the velocity level - a simple QP based controllers expressed at the acceleration level - a cartesian jogging demo using an acceleration QP and considereing joint limits - a trajectory tracking controller at the Cartesian level - a trajectory tracking controller at the Cartesian level including path constraints and a target constant velocity - a joint states estimation algorithm using a QP expressed at the jerk level or a Savitsky-Golay filter

Release Contributions: Initial version

URL: https://gitlab.inria.fr/auctus-team/people/sebastiendignoire/protected/pop-art

Contact: Vincent Padois

7.2 New platforms

7.2.1 Maze teleoperation

Participants: Lucas Joseph.

A new platform has been developed to demonstrate teleoperation modes. Participants are tasked with maneuvering a vial through a maze using a teleoperating device. Two types of haptic guidance were provided for the task: one without any guidance and another utilizing the guiding tubes tested by Alexis Boulay in his recent experiments. While the platform was initially designed for general public use, it could be improved for research applications. Many software developed by the team for haptic guidance are used for this platform.

7.2.2 evaLuation Of hapTic guidance on teleopeRation (LOTR)

Participants: Alexis Boulay, Margot Vulliez, David Daney.

Teleoperation allows remote task execution in environments inaccessible or hazardous to humans. While offering significant benefits, the physical separation between the operator and the workspace often leads to reduced performance and increased workload due to a lack of feedback. Haptic guidance addresses these challenges by using haptic devices to apply forces that direct the operator toward a task goal. By offering different reaching tasks' scenario in a vertical farming context, this setup was used to compare conventional haptic guidance methods from the literature, to evaluate a unified haptic guidance model called the ruling guidance, and to highlight the impact of environmental conditions and the guidance models on the human-robot interaction, in terms of task performance and safety, as well as human comfort and trust.

7.2.3 expePacbot

Participants: Loic Mazou.

To study the effects of responsibility, body position, and eye position during a collaborative task with a robot, a platform has been designed for creating Lego patterns in collaboration with a robot. This platform was developed as part of the Pacbot project and is intended for use by researchers involved in this joint collaboration. The platform uses software developed by Loïc to detect the Lego configurations via a standard RGB camera (oakInterface and happypose_exemples). It also features a Panda robot from Franka Emika (panda_qontrol_ws) or a Yumi robot (yumi_qontrol_ws), which performs the collaborative tasks.

7.2.4 Bipetto: a serial-parallel robotic leg prototype

Participants: Virgile Batto, Margot Vulliez.

The platform consists of the prototype of one serial-parallel robotic leg. It is located at LAAS-CNRS and is part of our collaboration with the Gepetto team. It was designed by using the co-design method 8.4.6 to optimize the dynamic performances of a bipedal walking robot. This platform aims at evaluating the leg's design, in terms of motion accuracy and force capability, before we make a complete prototype of the bipedal robot. It will also validate the simulation and the robot models used during the optimization process.

8 New results

8.1 Human Factors and cognitive approaches in human/system interactions

8.1.1 Attention Sharing Handling Through Projection Capability Within Human-Robot Collaboration

Participants: Benjamin Camblor, Lucas Joseph, Jean-Marc Salotti, David Daney.

The link between situation awareness (SA) and the distribution of human attention, has been explored within a human robot collaboration framework. According to (Endsley, 1995), SA is divided into three levels: perception, comprehension and projection. It is involved in the process of making decisions and carrying out actions in a dynamic environment. This work investigates three hypotheses. First, that the ability to project a robot's future actions improves performance in a collaborative task. Second, that the more participants are involved in tasks in a collaborative environment, the better their SA will be. Finally, that the use of a robot's non-verbal communication motions attracts a participant's attention more promptly than if the robot remains motionless. A within-participants study has been designed to investigate our three hypotheses. Participants were asked to perform a collaborative task with a robot (Franka Emika Panda robotic arm). It required them to assist the robot at different moments while they were engaged in a distracting task that was catching their attention (tower of Hanoi puzzle). These moments could either be anticipated and taken into account in the human decision-making and action loop or not. Lastly, the robot could either use non-verbal communication gestures to draw human attention or not. The results have demonstrated the significance of considering the human capability to project a robot next actions in their own personal attention management. Moreover, the subjective measures showed no difference in the assessment of SA, in contrast to the objective measures, which are in line with our second hypothesis. Finally, it seems that standing stationary can be considered a gesture of non-verbal communication. In the present work, robot waiting was more salient in capturing human attention when the robot remained motionless rather than making a signaling motion. The most important part of the work had been carried out last year but the valorization occured in 2024 with Camblor's thesis and a publication in the International Journal of Social Robotics [7].

8.1.2 Decision making with Delphi method

Participants: Jean-Marc Salotti, Ephraim Suhir.

An international collaboration has been implemented with Ephraim Suhir, senior researcher from Portland State University, expert in risks modeling and statistics, in order to address the problem of defining and combining complex heterogeneous criteria for the assessment of a teleoperated robotic task, considering task performance, reliability, safety and ergonomics. The Delphi method, a process of arriving at group consensus by providing experts with rounds of questionnaires, as well as the group response before each subsequent round, has been applied. The task was to teleoperate a heavy mobile robot in a shed using a tablet-style control interface. A consensus emerged among 8 experts, who selected the criteria of duration, number of trajectory corrections and feeling of the operator. Weights have been proposed for each criterion and statistical tools have been used to evaluate the consensus. This work has been published in the Journal of Field Robotics [12].

8.1.3 Modeling of Human visuo-haptic perception

Participants: Rémi Lafitte, Margot Vulliez.

Reliable visual and haptic feedback are known to improve teleoperation tasks. Better understanding human perception could help to develop feedback strategies that better inform the human operator during human-robot interaction. In parallel, psychophysic experiments have suggested that the brain combines visual and haptic estimates of environmental properties (e.g., object size) in a statistically optimal fashion. Whether this sensory integration still holds in a more challenging environment, such as for teleoperation, remains unknown. We are developing a psychophysic experiment, in healthy adults performing teleopration estimation tasks, to test this hypothesis. We will notably assess if integrating the perceptual estimates of an individual operator in the feedback process can help the latter to better perform a common telopration pick-and-place task. The project is conducted in collaboration with the CeRCA-CNRS at the University of Poitiers.

8.1.4 Legibility and predictability of haptic guidance in robot teleoperation

Participants: Benjamin Camblor, Margot Vulliez.

Haptic guidance is a method to assist a human operator performing tasks in teleoperation through force feedback. Taking into account human factors and individual preferences is crucial when designing such haptic assistance. It can modify the perception and understanding that humans have of the robot's assistance behaviour, i.e. the cognitive transparency of the robot.Specifically, making the robot actions more predictable and/or more legible can highly impact the understanding of the robot's behavior during human-robot interaction. The predictability of an action is linked to its similarity to the action that the human agent would expect for a given objective (action deduced from its goal). Conversely, an action is legible when it enables the human to predict the objective or intention it expresses (goal deduced from the action). The project aims at evaluating the impact of different haptic guidance trajectories on the legibility and predictability of the robot's assistance. It has been initiated with a literature review on legibility, predictability and cognitive transparency of robot motion and haptic feedback in teleoperation. We are currently designing an experimental protocol and platform to study how different haptic guidance can be more or less legible and predictable, during assisted teleoperation scenarios.

8.1.5 Understanding Agency in Human-Robot Collaboration

Participants: Alicia Barsacq, David Daney, Jean-Christophe Sarrazin.

In cognitive neuroscience, and more specifically in neuroergonomy, recent studies have demonstrated that a system's transparency depends on the user's ability to activate agency mechanisms, enabling control over the system's behavior. Agency appears to be strongly linked to prediction mechanisms, as reported in numerous studies.

The thesis of Alicia Barsacq investigates agency in the context of a collaborative task between a robot and a human agent, with a particular focus on the impact of different robotic assistive modalities. The objective is to determine the most effective feedback to stimulate the agent's predictive mechanisms and enhance collaboration. The experimental study will primarily explore haptic feedback as a teleoperative assistive modality.

This thesis is co-supervised with ONERA as part of the PEPR O2R program

8.2 Human Behavior Analysis

8.2.1 Study of Motor Variability

Participants: David Daney, Vincent Padois, Pauline Maurice, Jonathan Savin.

This long term research project led to a main action in 2024: the analysis of the experimental results obtained during the experimental campaign of 2023 (MOVER). These results are encouraging as they demonstrate that motor variability depends on some features of the task, especially pace and direction of the movement. Moreover, the observed motor variability is high enough to induce changes in biomechanical risk factors as estimated through standard ergonomic scores [18]. The analysis of the results will be pursued in 2025, potentially within the framework of the INTRO project submitted to the ANR yearly call in collaboration with INRS and the LARSEN team in Nancy.

8.2.2 Searching for best-fitting musculoskeletal models approximating an individual's upper limb force capacities

Participants: Gautier Laisné, Jean-Marc Salotti, Nasser Rezzoug.

Upper-limb force feasible set: theoretical foundations and musculoskeletal model reconstruction. In biomechanics, human hand force capacities refer to the set of feasible forces exertable at the hand considering arm posture and muscle tensions. In physical Human-Robot Interaction (pHRI), knowing the operator's force capacities allows the robot to adjust its assistance to avoid exceeding force limits. Using a musculoskeletal model representing a human upper-limb, force capacities can be described as a 3D polytope called the force polytope. This work explored first, in silico, force polytopes computed in three postures to personalize a musculoskeletal model through a non-differentiable and non-convex optimization problem. In order to solve this optimization, derivative-free algorithms have been used. They learn a model distribution in the search space and uses sampling to understand the function topology, allowing local researches to give better solutions, without assuming the function to be differentiable: in genetic algorithms, the model is a set of good solutions and the sampling is done through variations on solutions; and in SRACOS, the model is a hypercube and the sampling is from the uniform distribution in the hypercube. It learns to classify solutions as either positive or negative, using reinforcement learning described as a Markov decision process. Interesting results have been obtained enabling a reconstruction of muscle parameters. An experiment has also been implemented to collect real maximum forces exerted at the hand by human operators. A similar approach was used to identify the parameters with promising results. This work started 3 years ago with Gautier Laisné's PhD and concretized with the defense of the doctoral thesis in December 2024 [20]. The resultst will be published in 2025.

8.3 Human Robot Interaction

8.3.1 Re-expression of manual expertise through manual control of a teleoperated system

Participants: Erwann Landais, Vincent Padois, Nasser Rezzoug.

In the thesis of Erwann Landais which was defended in December [21], we studied how teleoperation can allow for the remote expression of technical gestures, with chemistry as a potential applicative domain. Indeed, teleoperation enables a task to be carried out remotely by a human expert. This remote control is often a guarantee of greater safety and comfort, or simply of feasibility in hazardous environments. However, it can also mean a loss of efficiency, or added complexity. To avoid these pitfalls, it is necessary to consider 1) what constitutes an operator's expertise for a given task, 2) the constraints encountered in carrying it out, and 3) the form of a teleoperation system adapted to it. An example of a task that could benefit from teleoperation is the task of finding solvents for chemical compounds, which is one of Syensqo's areas of expertise. This involves characterizing the solubility of a solute in a set of solvents, in order to determine the optimum solvent for that solute. This task, based on visual, cognitive and manual expertise, is performed by a small number of expert technicians. Performing this task relies on an empirical, tedious and sometimes dangerous process, motivating the distancing of technicians from the experimental environment through robotic assistance. Using this task as a case study, the thesis of Erwann Landais aimed at answering the following questions : on the one hand, how can an operator's expertise be preserved when performing a task using a teleoperated system ? And on the other hand, how can the suitability of a teleoperation solution for performing an expert task be assessed ? To answer these questions, a broad-spectrum literature review was carried out and two experimental studies were conducted. While the first study studied semi-automatic manipulation protocols, in the second study, which restults were analysed in 2024, a robot was designed to achieve a range of motion similar to that observed in technicians, and intuitive interfaces were used to define the desired movement of the vial in real time. The study shows that controlling the robot via these interfaces does not achieve an efficiency similar to that of the manual mode. However,the performance achieved is encouraging, and the study identifies several avenues of improvement for the efficient and reliable deporting of the technical gesture in chemistry. Finally, beyond the application framework, this work establishes a comprehensive methodology for evaluating the performance of teleoperation modalities.

8.3.2 A comparative study of haptic guidance methods, toward a generic guidance model

Participants: Alexis Boulay, Benjamin Camblor, Margot Vulliez, David Daney.

This work is within the framework of the collaboration with the Farm3 company. Performing remote tasks through a teleoperation system can be assisted through haptic guidance, a force feedback computed based on a virtual geometric constraints to help the user to follow a given behavior (task trajectory, safety area,...). If such haptic guidance methods are commonly used in the literature, no study has clearly defined which guidance model is the most suitable with respect to different tasks, environments, or user expertise.

Evaluation of user interaction with haptic guidance We conducted a user study, based on the LOTR platform 7.2.2, where 28 volunteers performed reaching tasks in a farming-shelf environement. The experimental conditions have varied the difficulty of the task, the environmental constraints, and the guidance model used to compute the force feedback (spring-damper, guiding tube, potential field, and ruling guidance) [23]. The experiment showed a diversity of user preferences regarding the haptic guidance model and the environment. This user study highlights the importance of developing an adaptation methodology that would provide the most appropriate haptic guidance to the user. For such an adaptation process, we have introduced quantitative metrics to evaluate performance, safety, comfort, and trust of the user during their interaction with the haptic system. Future works will focus on dynamically adjusting the guidance during the task execution to improve these interaction metrics.

The generic model of the ruling guidance The literature presents several haptic guidance models (notably spring-damper, guiding tube and potential field). But the lack of a generic formalism and the specialised nature of these different models make it difficult to use them in complex tasks and dynamics environments. To overcome this, we have proposed a new generic and parameterized guidance model called ruling guidance. The user experiment on the LOTR platform, demonstrated that the ruling guidance effectively encompasses classical haptic guidance behaviors. It therefore provides mechanisms for adapting the guiding force with respect to environmental conditions and human interactions.

8.3.3 Adaptive haptic guidance during human-robot interaction

Participants: Alexis Boulay, Anqiu Hu, Margot Vulliez, David Daney.

Conventional haptic guidance are computed from a path that should help the human while performing the task. This guidance path is often fixed and preplaned in advance based on an approximate knowledge of the environment, estimated from the sensors of the robot. It, therefore, may be imperfect with respect to the task. Moreover, it does not take into account the individual variability of the human performing the task. We have started to develop new mechanisms to deform the guidance path based on the user interaction, during the execution of the task, whether from a geometric or a dynamic point of view. Different deformation models are compared, such as elastic-band paths or Bezier curves. A parallel study has been conducted to extract new guidance trajectories from the human input motion, for the robot to learn new tasks by demonstration. We compared two different dynamic representations of task motion that can be used in the learning process: Dynamical Movement Primitive and Probabilistic Movement Primitive.

8.3.4 Effect of an Exoskeleton on Precision in Simulated Welding

Participants: Alicia Barsacq.

Alicia Basarq participated in a study conducted in collaboration with the Wearable Lab of the Sant'Anna School of Pisa. This research focuses on the effect of an upper-limb exoskeleton on precision during a simulated welding task. A scientific communication has been written to highlight these findings.

8.4 Robotics and control

8.4.1 Parametric Trajectories and Measurement Error in Inverse Optimal Control

Participants: Ahmed-Manaf Dahamni, David Daney, François Charpillet.

Inverse optimal control (IOC) is a growing field of research that has gained significant traction in human motion prediction and learning. However, current methods for solving IOC have several problems ranging from computation time to handling noisy data. This work builds upon the foundation laid in [30] in their attempt to explain the IOC through the lens of Karush–Kuhn–Tucker (KKT) optimality conditions and the concept of singularity curves. This work, presented in [13] tackles the issue of finding metrics to relate parametric representations of trajectories to discrete measurement error.

8.4.2 On the robustness of Projected Inverse Optimal Control

Participants: Ahmed-Manaf Dahamni, David Daney, François Charpillet.

Direct optimal control allows generating a trajectory by optimizing a cost function. We continue to work on the inverse approach, which aims to identify the weights of this function from an observed trajectory. In recent years, we have proposed a method called Projected Inverse Optimal Control (PIOC), which reduces the problem to a projection onto a hypersurface describing the singularities of a matrix. Its mathematical characterization can take different forms, and its evaluation can lead to numerical instabilities as the dimensionality of the observed trajectory representation increases. This year, we have worked on various solutions to evaluate this singularity and its derivative in order to enhance the robustness of PIOC.

8.4.3 Model Predictive Control for shared human-robot tasks

Participants: Elio Jabbour, Margot Vulliez, Vincent Padois.

Over the last year, we developped a Model Predictive Control-based Blending (MPC-B) approach for shared control in teleoperation, aimed at overcoming limitations of traditional Linear Blending (LB). The method frames blending as a constrained optimization problem, ensuring compliance with task and safety constraints while enabling smooth control transitions. By predicting robot motion over a receding horizon, MPC-B anticipates and enforces constraints on position, velocity, and acceleration.

A comparative evaluation was conducted through simulations and real-world pick-and-place experiments using a Franka Emika Panda robot. Results showed that MPC-B significantly enhanced task accuracy, safety, and motion continuity while reducing human effort. By formulating blending as a constrained optimization problem, the MPC-B method ensured compliance with position, velocity, and acceleration constraints, offering smoother, more predictable robot motions. The evaluation metrics highlighted the improved repeatability, constraint adherence, and overall system performance under MPC-B. Additionally, users experienced greater trust and comfort in shared control with MPC-B, as evidenced by increased reliance on assistance.

The study shows the potential of model predictive blending for safer and more efficient human-robot collaboration, with future work focusing on adaptive authority allocation and uncertainty environment modelling.

A technical report on this work is available in [24].

8.4.4 Dynamic authority distribution in haptic shared control

Participants: Jacques Zhong, Margot Vulliez.

Teleoperation of robotic manipulators aims at combining the expertise of the human operators and the assistive capabilities of the robotic system, in a variety of industrial activities where the human should stay afar from the work area for better security and ergonomics. In this context, an important challenge lies in how two agents (i.e. the human and the assistance) share the control of the teleoperated robot. While the assistance tries to predict the intent and adapt to the human actions, the human and assistance behaviors may differ due to their own physical capabilities, different task strategies, or incomplete models of the environment. Therefore, we want the resulting robot behavior to minimize the conflicts between the human and the assistance. In the shared control community, this problem is described as an arbitration problem, which consists in correctly adjusting the level of control authority between the human and the assistance. This authority level should be adjusted dynamically during the activity, as the human may need to take over the assistance, for example when there is an unexpected obstacle or a change of target. This work was initiated through an exploratory study of possible methods to solve this authority-distribution problem :

- a bibliographic research on shared control, shared autonomy and more specifically learning-based approaches that dynamically adapts the authority level based on past interactions between the human and the robot through the teleoperation device. Later works aim at exploring whether learning-based approaches can help with finding the complex relationship between human-assistance behaviors and the authority level.
- the implementation of approaches based on control theory and optimization, to dynamically adjust the authority level, done in a simple simulation. The implemented methods will further be tested and validated on a real teleoperation system to assess their performances.

8.4.5 Towards interaction control through tactile feedback

Participants: Sebastien Kleff, Vincent Padois.

Sebastien Kleff, in collaboration with Vincent Padois, submitted a Marie Skłodowska-Curie Action (MSCA) project on Tactile Adaptation for Contact-based Teamwork and Interactive Control Strategies (TACTICS). This project is based on the observation that so-called "collaborative" robots lack the adaptability required for effective human-robot collaboration (HRC). In particular, their physical interaction skills are limited to the preservation of human safety, which drastically reduces their pertinence and teamworking capabilities. The proposed research projectr targets this fundamental limitation by augmenting their sensing apparatus with tactile sensing. Specifically, TACTICS will develop a control architecture for HRC that systematically exploits tactile information to adapt online the robot behavior in contact with changing environments. This project will 1) extend modern optimal control with tactile feedback, 2) learn a multimodal human intention estimation framework 3) design tactile-informed adaptation mechanisms. This interdisciplinary project is expected to result in a versatile control architecture allowing cobots to adapt to the high variability of tools and human behaviors encountered in industrial manufacturing.

In order to build the TACTICS project upon solid methological tools, three main actions have been led:

- in collaboration with the Machines in Motion Laboratory at NYU (Armand Jordana, Avadesh Meduri and Ludovic Righetti), the Willow team at Inria Paris (Justin Carpentier) and the Gepetto team at LAAS-CNRS (Nicolas Mansard), Sebastien Kleff benchmarked the numerical optimal control solver based on Sequential Quadratic Programming mim_solvers against state-of-the art. A manuscript was re-submitted to IEEE Transactions on Robotics (T-RO) in October 2024 with additional results addressing the editor's comments, such as a benchmarking of our Quadratic Program (QP) solver against state-of-the-art QP solvers HPIPM and OSQP. S. Kleff actively contributed to the writing of the re-submission and the implementation of the benchmarks.
- Sebastien Kleff worked on extending the force feedback MPC framework developed during his PhD research to constrained tasks. This work aims at producing additional experimental results in order to re-submit our manuscript to IEEE T-RO. In particular, we developed and maintained the

"force_feedback_mpc" library 7.1.7 to allow force constraints and collision avoidance constraints between the robot and workspace obstacles. An experimental campaign was carried out by S. Kleff and A. Jordana at New York University in November 2024 in order to collect those additional results using the Machines in Motion Laboratory infrastructure.

- Sebastien Kleff started a state-of-the-art on both control methods for tactile interaction and tactile sensing technologies. Several contacts and scientific discussions have been undertaken with leading research teams in this domain.

8.4.6 Optimization and design of bipedal-robot leg architectures

Participants: Virgile Batto, Margot Vulliez.

The *legged-robot codesign* PhD project, in collaboration with the Gepetto team at LAAS-CNRS, aims at developing AI-based tools to help in designing a new leg architecture for a dynamic walking robot.

Optimization of new serial-parallel leg architectures New serial-parallel leg designs have been proposed and optimized in terms of dynamic capabilities. The optimization of these architectures was based on the Cleo software we developed for Closed Loop Architecture Optimization [22]. It takes as input the conceptual architecture design of a robot leg and returns a set of solutions for the mechanical architecture and actuation, by using an evolutionary optimization strategy with respect to design constraints and locomotion-task requirements. Prototypes of the proposed designs were made to evaluate the accuracy (position, flexibility, force) and the overall feasibility of the legs generated by the optimization algorithm. It demonstrates the usefulness of such a codesign method for leg design. This work results in the developement of the Bipetto experimental platform 7.2.4.

Design of parallel actuation for legged robots Dynamic legged robots can comprise parallel mechanisms in their leg kinematics to relocate the actuators close to the hip and reduce the weight of moving parts. Such parallel mechanisms must be finely optimized that the robot meets the required capabilities to perform different locomotion tasks. Such nonlinear actuation systems have been designed to enhance the performances of the developed bipedal robot leg. In a codesign process, the overall capability of a robot with parallel actuation must be evaluated through the simulation of the robot behavior with appropriate control strategies. We evaluated our parallel-actuation design with a new compatible control algorithm [26].

8.4.7 Online approach to near time-optimal task-space trajectory planning

Participants: Antun Skuric, Nicolas Torres, Vincent Padois, Lucas Joseph, David Daney.

Pursuing the work on robot capacities evaluationn undertaken in the thesis of Antun Skuric, we have developed an online approach to near time-optimal task-space trajectory planning. This work tackles the problem of underestimating true robot capabilites, leading to suboptimal use of time, energy and material resources. Indeed, conforming to safety standards often limits collaborative robots' performance and size, restricting their applications despite their capabilities. Planning their motions in human environments involves a trade-off between optimal trajectory planning and quick adaptation to dynamic, unstructured spaces. Traditional trajectory planning methods either use simplified robot models and sacrifice robot's abilities for computational efficiency, or exploit robots' abilities fully but have high computational complexity and rely on substantial pre-computation. In this we work, we introduce an approach for trajectory planning that exploits robot's full motion abilities while planning on-the-fly. In each step of the trajectory execution, it evaluates robot's movement ability using polytope algebra and calculates a time-optimal Trapezoidal Acceleration Profile (TAP) on the remaining trajectory. The method is shown to be near time-optimal (around 5% slower trajectories) by benchmarking it against the state-of-the-art time-optimal method TOPP-RA. It is also shown to be able to reach higher velocities (able to plan up to 100% of the robot's kinematic limits) while at the same time having lower tracking error (under 4mm) than traditional Cartesian Space planning methods. A mock-up experiment demonstrates its efficiency in collaborative waste sorting using a Franka Emika Panda robot.

This work [27] has been recently re-submitted to the IEEE Transactions on Robotics journal.

8.4.8 Solving semi-constrained end-effector path planning problems

Participants: Guillaume De Mathelin De Papigny, Vincent Padois.

As a follow-up to the Plan de Relance with the SME Aerospline, we have continued our work on proposing a compuationally efficient algorithm to solve semi-constrained end-effector path planning problems. This method, aiming at finding motion solution for robots evolving in highly constrained environements while presenting some level of task redudancy, has been formalized and a technical report on this work is available in [25].

8.4.9 Performant Optimization Problems for Advanced Robot Trajectories

Participants: Sébastien Dignoire, Vincent Padois.

As a wrap-up to the Plan de Relance with the start-up Fuzzy Logic, we have developped a set of examples implementing methods dedicated to advanced robot motion generation through efficient constrained optimization formulation. More precisely, these tools come as ROS workspace for the QP-based control of robots using Pinocchio 7.1.8.

9 Bilateral contracts and grants with industry

9.1 Airbus

Participants: David Daney, Vincent Padois, Sebastien Kleff.

The collaboration aims to design a constellation of mini-satellites and one of the challenges is to rethink their production, in particular through robotic assistance of operators. In this project, we have developed a coupled model of human-robot physical capabilities.

Project in a nutshell:

- Consortium : AUCTUS@Inria, Airbus
- Funding : BPI
- Duration : 2020 – 2024

9.2 Solvay

Participants: Erwan Landais, Vincent Padois, Nasser Rezzoug.

Project in a nutshell:

- Consortium: AUCTUS@Inria, Solvay
- Funding: Région Nouvelle-Aquitaine, ANR, Solvay, CNRS
- Duration: 2020 - 2024

Since 2020, we have developed a long term collaboration with the chemical company Solvay in order to help them in the digitalization and robotization of their productions. Our interlocutors are researchers of their Laboratory Of the Future (LOF) on the theme of collaborative robotics, seen as an important way to assist their operators and secure their potentially dangerous actions. The first objective is to develop a cobotic solution to follow an operators' work step by step by proposing an assistance available at the user's request in a constrained environment. This project has led to a bilateral contract and to the participation in the ANR Pacbot. In addition, this collaboration supported the PhD thesis of Erwann Landais through the Miels regional project.

9.3 Farm3

Participants: Alexis Boulay, David Daney, Margot Vulliez.

We collaborate with Farm3, a start-up company specialized in vertical farming, since 2020. The company develops a robotized vertical farm, the Cube, to grow plants in a controlled environment through ultrasound-based techniques. Agronomists and farmers can remotely act on the plants through a teleoperation system, to perform expert tasks (seedlings, pollinating flowers, measuring data...) without polluting the sensitive growth environment.

After preleminary results of a master's internship in 2021, a contract was signed with Farm3 in 2022 to start a PhD project. The PhD thesis aims at developing co-control approaches to assist the agronomists/farmers in teleoperated vertical agriculture. We first analyze specific farming tasks, to automate the simpler ones (moving a pot, taking pictures of the plants, ...) and determine the expert actions that must be preserved. We develop assistive control methods, based on haptic guidance, to help the operator to perform the remote tasks through proper feedback. We specifically focus on task/environement variability and constraints and user preference to adapt the guidance to increase performance, comfort, and safety of the teleoperation.

Project in a nutshell:

- Consortium: AUCTUS@Inria, Farm3
- Funding: Farm3, ANRT (CIFRE)
- Duration: 2022-2025

9.4 Fuzzy Logic Robotics

Participants: Sébastien Dignoire, Vincent Padois.

Started in 2022, the partnership between AUCTUS and the robotics company Fuzzy Logic Robotics has two main objectives. On the one hand, the collaboration provides Fuzzy Logic Robotics with a way to evaluate the pertinence of state of the art knowledge in robotics in their daily robotics practice. On the other hand, it brings to AUCTUS elements for the formulation of new scientific problems.

Project in a nutshell:

- Consortium: AUCTUS@Inria, Fuzzy Logic Robotics
- Funding: Plan de Relance
- Duration: 2022-2024

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Inria associate team not involved in an IIL or an international program

SHAARE Inria-KAIST associate team

Participants: Huseyin Tugcan Dinc, Dong-Hyeon Kim, Kwang-Hyun Lee, Jee-Hwan Ryu, Alexis Boulay, Jacques Zhong, Vincent Padois, David Daney, Margot Vulliez.

Title: Shared Haptics for Augmented Assistive Robot Expertise

Duration: 2024 ->

Coordinators: Margot Vulliez (Auctus) and Jee-Hwan Ryu (IRiS lab director @KAIST)

Partners:

- IRiS lab - Korea Advanced Institute of Science and Technology (Daejeon, South Korea)

Summary: Haptic teleoperation is a promising method to enable Humans and robots to jointly perform an activity. The human operator can safely and remotely control the robot while receiving feedback on the task interaction. Recent shared-autonomy concepts have been proposed in the literature to transfer part of the task from the human operator to the robotic agent to better assist him. Scientific challenges to tackle in such shared control support the need for a generic shared haptic framework. It will merge both haptic guidance (force feedback that assists the human to perform the task) and blending methods (control strategy that combines the human inputs and robot assistive skills). This global framework is the main research direction of the SHAARE associate team and will be our common baseline to share different developments and control techniques. The joint works specifically aims at augmenting robot assistive behavior in haptic teleoperation by improving haptic guidance, by dynamically distributing the authority between the human-robot agents, and by transferring expert skills from the human to the robot.

10.2 International research visitors

10.2.1 Visits of international scientists

Other international visits to the team

- Sébastien Kleff (New-York Univ. / LAAS) gave on March 21st a presentation on his most recent work on MPC-based force control.
- Majid Khadiv (TU Munich) gave on July 24th a presentation of his most recent work on applied and theoretical aspects of robot intelligence. This seminar was part of the R4 seminar series.
- Filip Bečanović (University of Belgrade) gave on November 14th a presentation of his most recent work on inverse optimal control.

10.2.2 Visits to international teams

Research stays abroad

Participants: Alexis Boulay.

Visited institution: IRiS lab - KAIST

Country: South Korea

Dates: September to November 2024

Context of the visit: In haptic guidance, the user is virtually guided on a pre-planed assistance trajectory, set by the user beforehand or generated offline from a task planner. However, it usually remains fixed during the task execution while the environment is uncertain and dynamically changing. The associate team develops approaches to deform the guidance trajectory based on the user interaction during the task, to improve the user comfort and trust in the assistance. The research visit focusqes on these approaches, and was done in collaboration with Kwang-Hyun Lee (Postdoc @KAIST) and Jee-Hwan Ryu (Full Professor @KAIST)

Mobility program/type of mobility: Collaborative research visit - SHAARE associate team

10.3 European initiatives

10.3.1 Other european programs/initiatives

Assistance Generation Techniques for multipurpose robot

Participants: Olivier David (CEA LIST), Margot Vulliez, Vincent Padois.

This collaborative work with the CEA LIST is part of the EUROfusion program, and explore robotic teleopration solutions to help in the maintenance of the future DEMO fusion-energy power plant. In the context of unplanned tasks, this work intends to provide a set of assistive generic tools and robot control solutions to help the operator to overcome unexpected situations in maintenance operations with a multipurpose robotic manipulator. User-interactive tools should provide a way to the operator to program remote handling tasks on the fly according to the context, the type and geometry of the equipment needing maintenance. Given the user-specified task, predictive controllers aim at locally computing the robot motion with respect to both the task trajectory and the human input motion (from the teleoperation device). Haptic feedback would be generated to guide the human on the planned trajectory.

Project in a nutshell:

- Consortium: CEA LIST, AUCTUS@Inria
- Funding: EUROfusion
- Duration: 2024

10.4 National initiatives

PEPR O2R - AS2, Robot motion with physical interactions and social adaptation

Participants: David Daney, Vincent Padois, Margot Vulliez, Alicia Barsacq, Jean-Christophe Sarrazin.

The objective of this structuring action is to rethink the problem of motion generation of robotic systems by addressing it in its globality and by redefining the research objectives in connection with the Human and Social Sciences. It aims on the one hand to develop technological solutions, innovative methods and software to provide these new generation robots with advanced planning and control capabilities of their movements and on the other hand to guarantee that the motor actions produced by these systems will be well adapted to humans. These systems will have to be able to interact physically with their environment and with humans to perform a wide panel of tasks ranging from agile locomotion to dexterous manipulation through collaborative tasks. Among the key objectives linked to these developments, these robots will have to be able to anticipate their movements but also to adapt them to react to unforeseen events and to implement robust control strategies to guarantee the successful execution of tasks and safety for the human. The question of movement autonomy of the machine and sharing of control during collaborative tasks will also be essential with regard to applications and needs. In all cases, it will be necessary to ensure the sustainability of the approaches developed with regard to environmental and societal challenges.

Project in a nutshell:

- Consortium: AUCTUS@Inria, Onera, Lirmm, univ. Picardie, willow@inria, Cerca, Pprime
- Funding: France 20230 (PEPR O2R)
- Duration: 2020 - 2032

BPI LiChIE

Participants: Sebastien Kleff, David Daney, Vincent Padois.

The LiChIE project (funded by BPI) aims to design a constellation of mini-satellites for optical Earth observation. Among many other topics, this requires to rethink the way sattelites are being produced in order to ease this highly complex process. There is actually an unprecedented economical and societal demand for robots that can be used both as advanced and easily programmable tools for automatizing complex industrial operations in contexts where human expertise is a key factor to success and as assistive devices for alleviating the physical and cognitive stress induced by such industrial task. Unfortunately, the discrepancy between the expectations related to idealized versions of such systems and the actual abilities of existing so-called collaborative robots is large. Beyond the limitations of existing systems, especially from a safety point of view, there are very few methodological tools that can actually be used to quantify physical and cognitive stress. There is also a lack of formal approaches that can be used to quantify the contribution of collaborative robots to the realization of industrial tasks by expert operators. Of course, in the state-of-the-art, existing works in that domain do consider some aspects of the current state of the operator in order to propose an appropriate robot behaviour. One of their conceptual limitations is to consider an a priori defined human-robot collaboration scenario where the expertise of the human operator is of importance but limited to a single operation. The consideration of larger varieties of tasks is rarely considered and, when it is, only a strict separation of the tasks to be achieved by each member of the human-robot dyad is considered. In this project, we propose to develop a coupled model of human-robot physical abilities that does not make any a priori with respect to the type of assistance. This requires to develop a parameterisable generic model of the potential physical link and implied constraints between the human operator and the robot. This model should allow to describe the task to be achieved by the human alone or using a collaborative robot through different interaction modalities. Online simulation of these scenarios coupled with ergonomic and performance indicators should both allow for the discrete choice of the right assistance mode given the task currently being achieved as well as for the continuous modulation of the robot behaviour.

Project in a nutshell:

- Consortium: AUCTUS@Inria, Airbus, Erems, iXblue, TEAMS@Inria, Onera
- Funding: BPI
- Duration: 2020 - 2024

ANR PACBOT

Participants: David Daney, Jean-Marc Salotti, Benjamin Camblor, Loïc Mazou.

The general objective of the project is to design a semi-autonomous cobotic system for assistance, able to choose, synchronize and coordinate tasks distributed between humans and robots by adapting to different types of variability in professional gestures, all by anticipating dangerous situations. The orchestration of tasks between a man and a robot is difficult because it must answer the question of the distribution of roles within the couple according to physical and decision-making skills and constraints as well as the consequences of their interactions. However, we cannot put the two actors at the same level: the robot has to adapt its actions to the work of an operator and, more precisely, to its motor and cognitive strategies that materialize through the quantifiable variability of professional actions. On the other hand, the very interest of the robot is to assist the operator in his phases of fragility while preserving his physical and mental integrity, in particular considering that human error is inherent in operator action. These considerations are, for Pacbot, the conditions necessary for the joint achievement of efficient work.

Project in a nutshell:

- Consortium: AUCTUS@Inria (Team Leader, David Daney - principal investigator), Laboratoire Informatique de Grenoble, Laboratoire Interuniversitaire de Psychologie (Lyon)
- Funding: ANR Funding (246 240 Euros for Auctus)
- Duration: 2021 - 2024

ANR JCJC ASAP-HRC

Participants: Célestin Préault (Associate Professor @CESI), Elio Jabbour, Jacques Zhong, Vincent Padois, Margot Vulliez.

This collaborative ANR project started in 2021 between the AUCTUS team at Inria, the RoBioSS team at the Pprime Institute (CNRS), and the CeRCA laboratory (CNRS). It aims at rethinking autonomy for shared action and perception in Human-Robot Collaboration, through transverse studies in robotics and cognitive sciences. More particularly, three scientific axes must be addressed to develop a human-centered and generic shared-autonomy framework: 1) study key features of Human-Robot perception-action mechanisms and identify multisensory integration processes involved in Human-Robot interaction. These human studies should constitute the baseline of robotic developments and shape the shared-autonomy scheme; 2) develop a shared perception between the different actors (humans and collaborative robots), according to their sensory data and involvement in the task. This shared perception will be based on a multimodal (haptic, visual) feedback mixture conveying information about the task, the environment, and the collaborators; 3) combine Human-Robot commands into a joint action toward the task goal. The human inputs will first be used to infer the operator intent and adapt the robot behavior. Then, the shared action will combine robot skills and human commands into a unified and consistent control objective.

Project in a nutshell:

- Consortium: AUCTUS@Inria (coordinator - Margot Vulliez), RoBioSS@Pprime (CNRS), Interactions@CeRCA (CNRS)
- Funding: ANR Funding (287 840 Euros)
- Duration: 2021 - 2026

Défi Transfert robotique, GRIP4ALL

Participants: David Daney, Lucas Joseph, Vincent Padois, Margot Vulliez.

As companies adapt to changes in the Factory of the Future, they need to modernise their working environments, in particular to improve logistics and transform industrial sites into flexible spaces incorporating intelligent machines and shared with human operators. The aim of the Grip4All project is to make industry more competitive by developing a new palletising cell adapted to the severe constraints imposed on the logistics flow when handling mixed products (of varying dimensions and weight) and arranging them on a pallet, without having to sort them manually upstream. This new type of palletising meets a strong demand from a number of sectors, notably mass distribution and the food industry. It meets the demand for handling heterogeneous products without imposing constraints on their packaging, which significantly improves productivity and eliminates tedious human tasks. No similar solution currently exists on the market. The flexible robotics issues addressed will be transposable to other logistics processes in the factory of the future. Grip4All is proposing a logistics line design that breaks with the state of the art, where lines are usually built by aggregating specialised cells: by their very nature, these limit the possibilities for logistics to evolve and adapt to a wide variety of products, and therefore also their sustainability in a context of sustainable development. The Grip4All approach is based on the use of the technological building blocks of robotics and new technologies in gripping, dynamic movement planning, AI perception and scheduling. The palletising cell is made flexible by using one or more 'augmented' manipulator arms with adaptive grippers, and by arranging and controlling the manipulator arms collaboratively in a dynamic environment. The system is based on a reactive and predictive control mode, as well as perception and scheduling algorithms that detect heterogeneous products and calculate their positioning according to their nature. The aim is to be able to handle a wide variety of products on the same pallet in real time, with adaptive gripping capabilities compatible with a wide range of products (weight, shape, nature, packaging), including two-arm gripping, and with vision-based detection and perception capabilities coupled with dynamic generation of movements for gripping and depositing products on the pallet. To meet this challenge, the project brings together 4 complementary partners: 2 industrial partners and 2 academic partners. The Fives industrial group, through its subsidiary FIVES Syleps, world leader in computerised and robotised mixed palletising, is seeking to stay ahead of its competitors and open up new markets. Subcontracting industrial partner Kannon MSD specialises in vision-based perception. The INRIA teams will contribute their technological building blocks in the form of software dedicated to reactive control in dynamic and human environments by Auctus, and to product scheduling by the Edge team. RoBioSS, a leading team in the development of high dexterity robotic hands and grippers, will contribute its mechatronic design bricks to increase robot flexibility. To ensure that the solution is acceptable and that human factors are taken into account, the consortium will be supported by the CERCA laboratory, which is working closely with the RoBioSS team has been working on this subject for over ten years..

Project in a nutshell:

- Consortium: AUCTUS@Inria (coordinator - David Daney), RoBioSS@Pprime (CNRS), Syleps@Fives
- Funding: France 2030 (952 000 Euros for Auctus)
- Duration: 2024 - 2026

Défi Transfert robotique, Extender

Participants: Vincent Padois, Margot Vulliez, Lucas Joseph.

In recent years, French academic research has demonstrated its excellence in collaborative robotics for manipulation (scientific publications, international recognition). However, the transfer of this expertise to smart manufacturing has not worked as well as expected: due to safety standards, cycle times are longer with lines involving humans and cobots than with conventional industrial installations (closed cages, no operator). A significant advantage of collaborative robots remains the ability for a human operator to perform complex unplanned tasks. This raises an opportunity in the collaborative robotics market: the sector of technical aids for the disabled. Cobots can meet the autonomy needs of people with disabilities whose arm or hand mobility is limited or non-existent. This opportunity leads the involved actors to consider the situations and specificities of users, in a co-construction approach. Constraints related to matching needs, adaptability to situations and uses, as well as the requirement for ease of use favor the adoption potential of developed technologies. The main objective is to deploy academic expertise in collaborative robot control on an innovative application for assisting people with disabilities, by betting on adoption favored by the right match between supply and demand. To achieve this, we will compare and integrate different types of controls and evaluate them in usage situations in an ecological environment. The target arm is the EXPLORER from the company ORTHOPUS. The consortium brings together 3 robotics laboratories (ISIR, Auctus, LAAS), 1 Handitech start-up – France 2030 program (ORTHOPUS), 2 preclinical evaluation centers (ESEAN & UCA), 1 research unit specialized in the study of technique usages (CETCOPRA). In an interdisciplinary perspective, this consortium federates academic, industrial, and medical expertise, and addresses technological, human, and societal issues. Throughout the project, users will be involved in a co-construction process. The program includes three stages. Stage 1 in the laboratory (6 months) for the adoption of common practices & materials and the development of a first prototype. Stage 2 (9 months) for Alpha tests with 1 to 2 patients and the progressive integration of modules. Stage 3 [9 months] for Beta tests with 4 to 5 patients, the consolidation of modules, and the exploration of other applications. Two original devices enrich the project and usage evaluation: participation in Cybathlon (international benchmarking) and a socio-anthropological study questioning the issues of co-design and technology adoption. To demonstrate the generality of technological modules, academic actors will work on demonstrators targeting demanding Industry 4.0 applications (smart workshop, glove box, demonstration programming). The project aims for a major societal impact on the inclusion of people with disabilities. Other impacts are anticipated with great attention: environment (from phase I by adopting SMART design principles), economy and employment (development of ORTHOPUS), people's safety (intrinsic safety of cobots, cybersecurity). With the project results, ORTHOPUS aims to become a major player in the development of a new generation of innovative robots serving motor disabilities. In synergy with other French robotics companies (Enchanted Tools, Pollen Robotics...), ORTHOPUS will thus contribute to the creation of a world-class robotic industrial sector.

Project in a nutshell:

- Consortium: ISIR (Sorbonne Université / CNRS), LAAS-CNRS, CETCOPRA (Université Paris 1 Panthéon-Sorbonne), Auctus (Centre Inria de l'université de Bordeaux, lead: Vincent Padois), Institut Pascal (UCA / CNRS, tutelle secondaire du CHU Clermont-Ferrand et membre de Clermont Auvergne INP), Orthopus et ESEAN AFP France handicap.
- Funding: France 2030 (324 000 Euros for Auctus)
- Duration: 2024 - 2026

LAAS-AUCTUS collaborations

Participants: Thomas Flayols (Research Engineer CNRS, GEPETTO@LAAS), Nicolas Mansard (Senior Researcher CNRS, GEPETTO@LAAS), Vincent Bonnet (Associate Professor, GEPETTO@LAAS), Virgile Batto, Margot Vulliez, David Daney.

We have built a close scientific relationship with the Gepetto team at LAAS CNRS (Toulouse) these past few years, through several collaborative projects:

- **Legged-robot codesign:** This PhD project aims at developing a generic codesign approach which will cover the hardware specification and dimensioning and the control strategy and requirements at once. We propose to leverage mastered AI-based methods (simulation, planning, optimization) to guide the mechatronic design cycles and to provide tools to assist designers. The transversal approach will be applied to the codesign of a new dynamic legged robot, as a balance between versatile but heavy robots (Atlas, Talos) and light robots limited to walking (Digit). Results of the year for this PhD project are presented in 8.4.6.
- **Inverse Optimal Control:** A collaboration on Inverse Optimal Control problem has started in pursuit of the results obtained in 8.4.2.

Project in a nutshell:

- Consortium: AUCTUS@Inria, GEPETTO@LAAS (CNRS)

- Funding: None
- Duration: 2021 - ongoing

LORIA-AUCTUS collaborations

Participants: Pauline Maurice , Jessica Colombel , François Charpillet , Jonathan Savin, Ahmed-Manaf Dahmani, Raphael Bousigues, David Daney, Vincent Padois.

We have established a close scientific relationship with Larsen at LORIA, in recent years, through several collaborative projects. Our main objective is to explore various approaches to the analysis of human movement, with a particular focus on two specific themes: the inverse optimal control in collaboration with the LAAS (see 8.4.2) and the study of motor variability in collaboration with INRS and Institut P' (see 8.2.1). In 2023, we submitted an ANR project focusing specifically on the latter theme, demonstrating our ongoing commitment to research and the development of new innovative perspectives in this constantly evolving field.

Project in a nutshell:

- Consortium:AUCTUS@Inria, LARSEN@LORIA (Inria-CNRS), INRS, Institut P'.
- Funding: None
- Duration: 2020 - ongoing

National visits to the team

- Alexandre Lê (Safran) gave on January 24th a presentation of his most recent work on symbolic tools apply on robotics design.
- Marine Desvergnes (CeRCA, Univ. Poitiers) gave on January 25th a talk on "Téléopération et charge mentale : évaluation de l'impact de différentes aides visuelles au cours d'un scénario de maintenance industrielle."
- Thomas Flayols LAAS, Toulouse CNRS Research Engineer at LAAS, Toulouse, gave on March 12th a presentation on "Ongoing research and mechatronic development on legged robots at LAAS: The ODRI open motor controllers and quadruped designs"
- Sylvie Michel and Emmanuelle Gagnou-Savatier (IRGO, Univ. Bordeaux) presented on May 2nd presented their latest results about the emergence of ethical consciousness in robotics research.

10.5 Regional initiatives

AAPR Perception-HRI

Participants: Cécile Scotto, Remi Lafitte, Benjamin Camblor, Margot Vulliez.

This regional project completes the ASAP-HRC ANR objectives with additional cognitive studies to improve the exchange of perceptive information during Human-Robot interactions. Such an exchange of information between the agents is required to communicate and coordinate together. We particularly focus on visual and haptic feedbacks, related to the task, the context, or the robot assistance, and given through a teleoperation device to perform an industrial task. Only a fine analysis and modeling of the human multisensory perception and integration processes can provide practical guidelines to determine the optimal mixture of feedbacks to implement in the human-robot interface. The project therefore aims at developing personalized mathematical models of the perceptive and sensorimotor integration of visuo-haptic informations, in interaction scenarios with a robot.

Project in a nutshell:

- Consortium: AUCTUS@Inria (coordinator - Margot Vulliez), Interactions@CeRCA (CNRS, coordinator - Cécile Scotto), RoBioSS@Pprime (CNRS)
- Funding: Région Nouvelle Aquitaine
- Duration: 2022 - 2026

ROBSYS - Robustness of Autonomous Systems

Participants: David Daney, Vincent Padois, Margot Vulliez, Jean-Marc Salotti.

Auctus is particularly involved in WP1 on Robustness of Control / Decision Systems and WP3 on Robust Human/Machine Interaction. It is also involed in WP6 through the co-advising of a PhD thesis with the Rhoban Team on robust legged locomotion. Finally, Auctus has been retained by the leader of WP8 as a "subject team" for study of the emergnence of ethical questions in the research process in Robotics. ROBSYS specializes in autonomous decision-making systems, including IoT devices, autonomous vehicles, and various robotic applications deployed in diverse environments. These systems, integral to Industry 4.0, operate in open settings such as disaster sites, agricultural fields, and households, making decisions based on approximate and partial information. Inherent errors in autonomy are acknowledged, highlighting the importance of robustness. For these critical systems, robustness goes beyond design and construction quality, requiring an understanding of the environment and its elements. Detection and prediction, from immediate ground characteristics to ethical and legal considerations, are crucial for adapting and planning actions. The complexity increases in the realm of artificial intelligence, where fault tolerance and auditability become challenging, especially in human interactions. Real-world machine learning experiences, rather than just simulations, are emphasized, posing limitations (frugal AI), yet underscoring the central role of data. In this context, the goal is to study fundamental issues overing all the functions of autonomous systems from different angles (formal methods, stochastic models, and model-based analysis) as well as to propose the design of experimentation prototypes and representative set-ups: Agricultural Robots, legged robots usable in exploration context including agriculture, swarms of autonomous systems, in particular for data collection (ground / air / infrastructures). Beyond these technical aspects, ROBSYS also aims at studying the ethical issues brought by the paradigm of autonomous systems as the concept of autonomy also questions the legal aspect in a deep and no less essential way.

Project in a nutshell:

- Consortium: LABRI, IMS, IMB, Centre Inria de l'Université de Bordeaux (AUCTUS, MNEMOSYNE), ONERA, I2M, IRDAP, IRGO
- Funding: Université de Bordeaux, Réseaux de Recherche Impulsion
- Duration: 2022 - 2025

Miels

Participants: Erwann Landais, Nasser Rezzoug, Vincent Padois, David Daney.

The main objective of the MIELS project is to develop innovative strategies to characterize and develop neoteric, non-toxic solvents through strategies that will enable to grasp the enormous quantity of required experimental tests all in insuring an absolute safety of the manipulator. For this purpose, we intend to work on two complementary routes, the development of solvent characterization methodologies and the integration of a cobotic approach in solvent handling and evaluation, with the ambition of merging these developments at the end of the project in order to draw as much synergy as possible. This project is built around teams with complementary competencies to achieve these objectives. UMR LOF and Solvay LOF have great experience acquired over several years of research the fields of solvent evaluation and robotics, whereas Auctus INRIA team has a strong expertise in collaborative robotics. By combining our competencies and expertise, the Miels project aims to merge all these fields in order to expand 1) the fundamental study of solvents and their characterization techniques including theoretical techniques, in particular for green solvents and 2) the development of the use of cobotics, in collaboration with Auctus INRIA team, for increasing the efficacy and safety of laboratory workers in industry, in particular those working on characterization of solvents.

Project in a nutshell:

- Consortium: AUCTUS@Inria, Solvay, LOF
- Funding: Région Nouvelle Aquitaine, Solvay
- Duration: 2020 - 2024

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair

- Margot Vulliez: Studio chair for the ACM International Conference on Tangible, Embedded and Embodied Interaction, TEI 2025, Inria - CNRS - Université de Bordeaux

Member of the organizing committees

- Vincent Padois: co-organizer of the "Human Movement Modeling for Human-Robot Interaction" workshop at the 2024 IEEE-RAS International Conference on Humanoid Robots in Nancy
- Vincent Padois: co-organizer of the "Journée Robotique industrielle @BordeauxCampus" with the department "Science de l'Ingénierie et du Numérique", the BEST and ROBSYS Research impulsion Networks from Université de Bordeaux, IMS, Talence, December 2024
- David Daney: co-organizer of the "Journée Robotique et éThique", Bordeaux, Octobre 2024.
- The team organized a collaborative robotics experimental session during the automn school "xiho24 : Expérimenter l'interaction humain-objet : théories, méthodologies, analyses", ENSC, Talence, October 2024

11.1.2 Scientific events: selection

Member of the conference program committees

- Vincent Padois was Associate Editor for the 2024 IEEE International Conference on Robotics and Automation

Reviewer List of conferences for which Auctus members have review activities

- 2024 IEEE International Conference on Robotics and Automation ICRA
- 2024 IEEE/RSJ International Conference on Intelligent Robots and Systems IROS
- 2024 International Symposium on Advances in Robot Kinmatics ARK

11.1.3 Journal

Member of the editorial boards

- Nasser Rezzoug: Journal of Biomechanics as representative of the French speaking Society of Biomechanics)

Reviewer - reviewing activities List of journals for which Auctus members have review activities:

- IEEE Transactions on Robotics
- IEEE Robotics and Automation Letters
- International Journal of Robotics Research
- Mechanism and Machine Theory
- IEEE Transcations on Haptics
- Journal of Mechanisms and Robotics
- International Journal of Social Robotics
- Journal of Field Robotics
- Springer nature
- Acta Astronautica
- Journal of Space Safety Engineering
- Futures
- International Journal of Disaster Risk Reduction

11.1.4 Invited talks

External

- David Daney: "Les technologies de la robotique au service de vos besoins industriels", DIHNAMIC, Bordeaux, july 2024.
- Margot Vulliez: "État de l'art scientifique et état de la technique industrielle : quels écarts et pourquoi ?", table ronde, Journée Robotique industrielle @BordeauxCampus, Talence, December 2024
- Vincent Padois: "L'humain dans la boucle de commande du robot collaboratif et inversement", Journée TS1-TS4 GDR Robotique "Contrôle Moteur pour l'Interaction Humain-Robot", Paris, October 2024
- Margot Vulliez: "Sécuriser les humains au travail sans les limiter, le cas de la téléopération", Journée Robotique industrielle @BordeauxCampus, Talence, December 2024
- Margot Vulliez: "SHAARE Inria-KAIST associate team: Shared Haptics for Augmented Assistive Robot Expertise", at the French-Korean workshop on AI, New Networks, Programming Languages and Mathematical Sciences, KAIST-KISTI-Inria, Daejeon - online, November 2024
- Margot Vulliez: "Some progresses in haptic shared control", at LAAS-CNRS Gepetto team seminar, Albi, June 2024
- Nasser Rezzoug: "Upper-limb biomechanical capacity modeling for human/robot interaction", Humanoids 2024 workshop on Human Movement Modeling for Human-Robot Interaction, November 2024
- Benjamin Camblor: "Expérience(s) en robotique collaborative", "Xiho'24 : Expérimenter l'interaction humain-objet : théories, méthodologies, analyses", Bordeaux (ENSC), October 2024
- Alexis Boulay: "A haptic guidance generic approach", Journée EDSPI - Poster presentation, Talence, February 2024

- Alexis Boulay: "From Virtual Fixtures to Active Constraints: Toward an adaptive and dynamic haptic guide", SHAARE KAIST-Inria associate team seminar, March 2024
- Elio Jabbour: "Model Predictive Blending in Shared Control", SHAARE KAIST-Inria associate team seminar, March 2024
- Virgile Batto: "Presenting The Battobot, A Dynamical Bipedal Robot", at JNRH, Nancy, November 2024
- Sebastien Kleff: "Introductory seminrar on Model-Preditive Control for Robotics" (3 sessions on 03/10/2024, 17/10/2024 and 14/11/2024).

Invited by Auctus

- Marine Desvergnes (CeRCA, Univ. Poitiers) gave on January 25th a talk on "Téléopération et charge mentale : évaluation de l'impact de différentes aides visuelles au cours d'un scénario de maintenance industrielle."
- Thomas Flayols (CNRS Research Engineer at LAAS, Toulouse), gave on March 12th a presentation on "Ongoing research and mechatronic development on legged robots at LAAS: The ODRI open motor controllers and quadruped designs"
- Sébastien Kleff (New-York Univ. / LAAS) gave on March 21st a presentation on his most recent work on MPC-based force control.
- The team of Jee-Hwan Ryu (IRiS lab @KAIST) participated to a joint seminar on March 25th within the framework of the SHAARE KAIST-Inria associate team led by Margot Vulliez
- Sylvie Michel and Emmanuelle Gagnou-Savatier (IRGO, Univ. Bordeaux) presented on May 2nd presented their latest results about the emergence of ethical consciousness in robotics research.
- Majid Khadiv (TU Munich) gave on July 24th a presentation of his most recent work on applied and theoretical aspects of robot intelligence. This seminar was part of the R4 seminar series.
- Alexandre Le gave on January 24th a presentation of his most recent work on symbolic tools apply on robotics design.
- Filip Bečanović gave on November 14th a presentation of his most recent work on inverse optimal control.

11.1.5 Leadership within the scientific community

- Vincent Padois is the representative of the Inria Program Agency and member of the creation and steering committee of the PEPR Robotics Acceleration.
- David Daney is the Deputy Head of Science at Inria centre at the University of Bordeaux, April-July 2024.
- David Daney is the Head of Science at Inria centre at the University of Bordeaux since July 2024.
- David Daney is a member of the Scientific Council of the GDR Robotics, the main organization for robotics researchers in France.

11.1.6 Scientific expertise

The Auctus team is involved in the "Aquitaine robotics" cluster, which brings together robotics players in Nouvelle-Aquitaine. David Daney and Jean-Marc Salotti respectively represent Inria and Ensc on the board of directors. David Daney is a member of the executive board. David Daney and Jean-Marc Salotti are respectively president and vice-president of the labelling committee which promotes all robotics projects for the Nouvelle-Aquitaine region.

11.1.7 Research administration

- Virgile Batto is Doctoral students' representative at the EdSys doctoral school since 2023
- David Daney is a member of of the Inria Evaluation Committee since April 2024.
- David Daney is a member of the France 2030 Robotics Committee.
- David Daney is member of the "Commission des Emplois de Recherche" for the Inria centre at the University of Bordeaux.
- David Daney is the coordinator of 3 working groups (GT) on the evaluation and on the creation of 3 Inria Projet-Teams for the Inria Evaluation Committee.
- David Daney is a member of the executive board of R4, a regional robotics network involving 12 research entities in the region of Nouvelle-Aquitaine, France.
- David Daney is the principal investigator of ANR Pacbot
- David Daney is the principal investigator of DTR Grip4All ANR/France 20230
- Vincent Padois is since september 2022 head of the "Commission des Développements Technologiques" for Inria centre at the University of Bordeaux.
- Jean-Marc Salotti is in charge of international relationships at ENSC.
- Margot Vulliez is member of the "Commission des Emplois de Recherche" for Inria centre at the University of Bordeaux, since January 2024.
- Margot Vulliez is the principal investigator of the ANR ASAP-HRC (2021-2026) and AAPR Nouvelle-Aquitaine Perception-HRI (2022-2027) projects.
- Margot Vulliez is the principal investigator of the SHAARE Inria-KAIST associate team (2024-2026) with the IRiS lab.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

- Licence: Virgile Batto, Robotics, 15h eqTD, L2, BUT GE2I, IUT of Toulouse, France.
- Licence: Margot Vulliez, Mechanical Design, 24h éqTD, L1, BUT GMP, IUT of Bordeaux, France.
- Licence: Margot Vulliez, Design Projects, 13h éqTD, L2, BUT GMP, IUT of Bordeaux, France.
- Master: Alexis Boulay, Projet Informatique Individuel, 6h éqTD, M1, Ensc, Bordeaux INP, France.
- Master: Alexis Boulay, Introduction à ROS2, 24h éqTD, M2, Enseirb, Bordeaux INP, France.
- Master: Benjamin Camblor, Fonction cognitives en situation et Handicap, 11.25 éqTD, M1 (S7), Master de Sciences cognitives et Ergonomie, Université de Bordeaux, France.
- Master: Gautier Laisné, Bases de l'intelligence artificielle, 16h éqTD, M1, École Nationale Supérieure de Cognitique.
- Master: Gautier Laisné, Projet de fin d'études, 9h éqTD, M2, École Nationale Supérieure de Cognitique.
- Master: Lucas Joseph, ROS, 44h éq TD, CESI, Bordeaux, France.
- Licence: Nasser Rezzoug, Biomécanique, 60h éqTD, L2, Faculté des Sciences du Sport (FSS), Université de Poitiers, France.

- Licence: Nasser Rezzoug, Biomécanique, 10.5h éqTD, L1, Faculté des Sciences du Sport (FSS), Université de Poitiers, France.
- Licence: Nasser Rezzoug, Biomécanique de la déficience motrice et du vieilliessement, 23h éqTD, L3, Faculté des Sciences du Sport (FSS), Université de Poitiers, France.
- Licence: Nasser Rezzoug, Aspects biomécaniques du handicap, 18h éqTD, L3, Faculté des Sciences du Sport (FSS), Université de Poitiers, France.
- Master: Nasser Rezzoug, Modalités de prescription de l'activité physique, 18h éqTD, M1, FSS Master APAS/IRHPM, Université de Poitiers, France.
- Master: Nasser Rezzoug, Analyse cinematique et dynamique du mouvement, 20h éqTD, M1, FSS Master APAS/IRHPM, Université de Poitiers, France.
- Master: Nasser Rezzoug, Métrologie, 16h éqTD, M1, FSS Master APAS/IRHPM, Université de Poitiers, France.
- Master: Nasser Rezzoug, Ergonomie du poste de travail, 23h éqTD, M1, FSS Master APAS/IRHPM/ et SFA Ingénierie biomécanique, Université de Poitiers, France.
- Diplome d'Etat de masseur kinesitherapeute : Nasser Rezzoug, Biomécanique, 21h éqTD, CHU et Université de Poitiers, France.
- Master: Jean-Marc Salotti, Bases de l'intelligence artificielle (ENSC 2A), 40h eqTD.
- Master: Jean-Marc Salotti, Apprentissage Automatique (ENSC 2A), 25h eqTD.
- Master: Jean-Marc Salotti, Interactions Humains Robots (ENSC 3A), 32h eqTD.
- Master: Jean-Marc Salotti, Planning (parcours robotique ENSC-ENSEIRB 3A), 15h eqTD.
- Master: Jean-Marc Salotti, Facteurs Humains et Ingénierie Cognitique (ENSC 3A), 28h eqTD.
- Master: Jean-Marc Salotti, supervision of projects and internships (ENSC 1A, 2A, 3A)and jury for oral presentations, 100h eqTD.
- Master: Vincent Padois, Literature review - What, Why and How?, 20h éqTD, M2, Enseirb/Ensc, Bordeaux INP, France.
- Master: Vincent Padois, Maintenance du futur - Cours introductif, 2h éqTD, M1, ENSPIMA, Bordeaux INP, France.
- Master: Vincent Padois, Maintenance du futur - Introduction à la Robotique, 10h éqTD, M2, ENSPIMA, Bordeaux INP, France.
- Master: Vincent Padois, Introduction à la Robotique, 2h éqTD, M1, Université de Bordeaux, France.
- Master: David Daney, Interactions Humains Robots, 6h eqTD, M2, Ecole Nationale Supérieure de Cognitique / Bordeaux INP, France.
- Master: David Daney, Mathématiques pour la robotique, 30h eqTD, M2, Enseirb/Ensc, Bordeaux INP, France.
- Master: David Daney, oral expression, 6h eqTD, M2, Enseirb/Ensc, Bordeaux INP, France.
- Master: Alicia Barsaq, Structures arborescentes, 46h eqTD, M1, Enseirb, Bordeaux INP, France.
- Master: Ahmed-Manaf Dahmani, Interaction humain robot, 16h eqTD, M2, Ensc Bordeaux INP, France.
- License : Ahmed-Manaf Dahmani, Initiation à l'algorithmique, 49h eqTD, L3, Enseirb, Bordeaux INP, France.

11.2.2 Supervision

PhD in progress

- Alexis Boulay (Farm3, Cifre), "Assister l'humain par un transfert de compétences au robot en agriculture verticale téléopérée", June 2022 -, David Daney and Margot Vulliez
- Virgile Batto (CNRS), "Intelligence artificielle pour la co-conception de nouveaux robots dynamiques à pattes : une approche de conception multidisciplinaire et générique", October 2022 -, Nicolas Mansard (LAAS-CNRS), Thomas Flayols (LAAS-CNRS) and Margot Vulliez
- Elio Jabbour (Inria), "Shared-autonomy control for improving Human-Robot collaborarion in haptic teleoperation", funding: ANR ASAP-HRC, October 2022-, Margot Vulliez, Célestin Préault (CESI) and Vincent Padois
- Ahmed-Manaf Dahmani (Inria), "Robust inverse optimal control for human motion analysis", funding: Inria, December 2023-, David Daney, François Charpillet (Inria Nancy)
- Marc Duclusaud (Université de Bordeaux, Rhoban), "Learning for walking humanoid robots", funding: RobSys, September 2022 - , Olivier Ly (Université de Bordeaux), Grégoire Passault (Université de Bordeaux), Vincent Padois
- Alicia Barsacq (Inria), "Etude des méthodes de feedback pour une interaction homme/robot agentive", funding: PEPR O2R, Septmber 2024 - , David Daney, Jean-Christophe Sarrazin (Onera)

PhD defended

- Benjamin Camblor, Exploitation du mouvement du robot pour améliorer la conscience de situation dans la collaboration humain-robot [19], January 2020 - April 2024,Jean-Marc Salotti and David Daney
- Erwann Landais, La téléopération comme moyen d'expression à distance du geste technique : application à la formulation en chimie [21],September 2021 - December 2024, Vincent Padois and Nasser Rezzoug
- Gautier Laisné, Upper-limb force feasible set: theoretical foundations and musculoskeletal model reconstruction [20], October 2021 - December 2024, Nasser Rezzoug and Jean-Marc Salotti

Masters and Final Year Projects

- Anqiu Hu: 6 months Master 2 internship on Dynamic Movement Primitives application to haptic guidance, February - July 2024, Alexis Boulay and Margot Vulliez
- Matteo Caravati: 6 months Final Year Project on the co-design of multipurpose modular robots, February - August 2024, Vincent Padois and Margot Vulliez
- Elina Perinet: 4 months Master 1 internship on the design of easily machinable parts for humanoid robot, March - July 2024 Virgile Batto and Thomas Flayols

11.2.3 Juries

PhD

- David Daney
  - Angelica Ginnante, Reviewer, Optimized design, analysis and kinematic control of highly redundant serial robotic arms, Genoa university (Italia) and école centrale de Nantes (France), 2024/01/17

  - Étienne Fournier-Aubret, Intérêt de la prise en compte des variabilités de l'activité et de l'acceptabilité dans le cadre d'une conception centrée utilisateurs des situations de travail collaboratives Humain-Robot, Université Greanoble Alpes, Psychologie du Travail et Ergonomie, 2024/07/08
  - Caroline Pascal, Reviewer, Robotized measurements : automated acoustical characterization of structures, école nationale supérieure de techniques avancées ENSTA, 2024/11/28
  - Mohamed Khalil Jabri, President of the Jury, Towards Better Efficiency and Generalization in Imitation Learning: A Causal Perspective, IMT Atlantique, 2024/12/04

- Vincent Padois
  - Filip Becanovic, Reviewer, Uncovering Optimal Control Strategies in Human Motion through Inverse Optimal Control, Université Paris-Est Créteil, 2024/02/29
  - Kelly Steiner, President of the Jury, Étude des mécanismes du contrôle sensorimoteur pour la spécification de nouvelles métriques d'évaluation du coût cognitif, Sorbonne Université / ONERA, 2024/03/18
  - Michele Cipriano, Reviewer, Generation and Control of Motion for 3D Humanoids and Steerable WMRs, Sapienza University of Rome, 2024/05/29
  - Alexis Poignant, President of the jury, Commande volontaire d'un manipulateur robotique d'assistance placé dans l'espace péripersonnel, Sorbonne Université, 2024/10/15

- Nasser Rezzoug
  - Ouadoudi Belabzioui Hasnaa, Reviewer, Contributions to the In-Situ Biomechanical and Physical Ergonomic Analysis of Workstations Using Machine Learning and Deep Learning Techniques, Ecole Normale Supérieure de Rennes, 2024/12/20.

HDR

- David Daney
  - Sylvain Guegan, Reviewer, Modélisation et conception en robotique d'assistance, Institut national des sciences appliquées de Rennes INSA, France, 2024/09/03

Recruitment

- David Daney participated in recruitment jury MCF, section 27, 60, IMT Altantique, May 22th, 2024.
- Margot Vulliez participated in recruitment jury MCF in Informatics, section 27, Université de Lorraine, Télécom Nancy, LORIA, May 6th, 2024.
- Margot Vulliez participated in recruitment jury MCF in Robotics, section 60, Université Toulouse 3, LAAS-CNRS, May 16th, 2024.
- Margot Vulliezparticipated in recruitment jury MCF in Robotics, section 61, SUPMICROTECH-ENSMM, Institut FEMTO-ST, May 21st, 2024.

11.3 Popularization

11.3.1 Productions (articles, videos, podcasts, serious games, ...)

- Margot Vulliez: Video storytelling, robotics research career, Numérixplore, September 2024, Poitiers.
- Margot Vulliez: Podcast speaker for "Désassemblons le numérique", Episode 10, Inria Bordeaux research center, September 2024, Talence.

11.3.2 Participation in Live events

Un scientifique une classe – Chiche ! Seminars to raise general awareness of science and research careers for high school student secondary students

- Vincent Padois, Lycée Borda, Dax (40), November 2024
- Vincent Padois, Experience report on the Chiche program, Online, Inria, October 2024
- Margot Vulliez, Lycée Borda, Dax (40) January 2024
- Margot Vulliez, Lycée Arnaut Daniel, Ribérac (24), November 2024

Classe transplantée Robot - CapScience / Les petits aventuriers du Numérique Presentation of robotic research to primary school students

- David Daney, CapScience, Côté Sciences Air&Espace, Mérignac, May 2024
- David Daney, CapScience, École Albert Schweizer, Bordeaux, Novembre 2024
- Vincent Padois, CapScience, Côté Sciences Air&Espace, Mérignac, March 2024
- Vincent Padois, CapScience, École Carl Vernet, Bordeaux, November 2024
- Vincent Padois and Alexis Boulay, Les petits aventuriers du Numérique, École Jean Jaurès de Villenave d'Ornon, April 2024
- Margot Vulliez, CapScience, Côté Sciences Floirac, October 2024

Fête de la Science

- Vincent Padois, Loic Mazou and Margot Vulliez, Creation of a modular disconnected robot for hands-on activities to discover robotics, Ateliers "Mouvement de robots, comment construire un robot pour faire une tâche ?", Circuit Sciences du Numérique en Nouvelle-Aquitaine, Oloron Sainte Marie (64), Saint Vincent de Tyrosse (40), Villeneuve sur Lot (47), Sarlat (24), October 2024

Nuit de la recherche

- David Daney, Engage with the public, explore the public's imagination in connection with research themes, and promote participation. In the style of speed dating, an exchange with small groups is organized around a presentation and an explanation of scientific topics. Cap Science, September 2024.

MIMM "Moi Informaticienne, Moi Mathématicienne"

- Margot Vulliez, Presentation and discussion about robotics research with secondary-school female students, MIMM,Inria Bordeaux research center, April 2024.

Journée des enseignants et enseignantes de NSI-SNT

- Margot Vulliez, Talk about robotics research and possible applications in high-school teachings, Inria Bordeaux research center, January 2024.

Les portes fermées

- David Daney, co-organize the event "Portes Fermées" at Inria centre at the University of Bordeaux, December 2024.

11.3.3 Others science outreach relevant activities

- Auctus team, Live demonstration of robot teleoperation in a maze with haptic guidance at Bordeaux City Hall within the framework of the **Journées RobNA – Robotique en Nouvelle Aquitaine**, co-organized by the Regional Research Network on Robotics, Pey-Berlan, Bordeaux, October 2024
- Lucas Joseph and Vincent Padois, Live demonstration of robot capacities vizualization using augmented reality at **Humanoids 2024**, Nancy, November 2024
- Alexis Boulay and Elio Jabbour, **AI4Industry**, Running a stand demonstrating haptic teleoperation, Enseirb, Talence, Jan 2024
- Vincent Padois Live demonstration of robot teleoperation in a maze with haptic guidance during the event "Portes Fermées" at Inria centre at the University of Bordeaux, December 2024

12 Scientific production

12.1 Major publications

[1] N. Benhabib, V. Padois and D. Daney. 'Securing Industrial Operators with Collaborative Robots: Simulation and Experimental Validation for a Carpentry task'. In: ICRA 2020 - IEEE International Conference on Robotics and Automation. Paris, France, 31st May 2020. DOI: 10.1109/ICRA40945.2020.9197161. URL: https://hal.inria.fr/hal-02418739.

[2] B. Camblor, N. Benhabib, D. Daney, V. Padois and J.-M. Salotti. *Task-Consistent Signaling Motions for Improved Understanding in Human-Robot Interaction and Workspace Sharing.* 6th Jan. 2022. URL: https://hal.inria.fr/hal-03513888 (cit. on p. 7).

[3] P. Maurice, V. Padois, Y. Measson and P. Bidaud. 'Human-oriented design of collaborative robots'. In: *International Journal of Industrial Ergonomics* 57 (2017), pp. 88–102 (cit. on p. 9).

[4] J. Savin, C. Gaudez, M. A. A. Gilles, V. Padois and P. Bidaud. 'Evidence of movement variability patterns during a repetitive pointing task until exhaustion'. In: *Applied Ergonomics* 96 (2021), p. 103464. DOI: 10.1016/j.apergo.2021.103464. URL: https://hal.archives-ouvertes.fr/hal-03280696.

[5] A. Skuric, V. Padois and D. Daney. 'Pycapacity: a real-time task-space capacity calculation package for robotics and biomechanics'. In: *Journal of Open Source Software* 8.89 (12th Sept. 2023), p. 5670. DOI: 10.21105/joss.05670. URL: https://inria.hal.science/hal-04316801.

[6] A. Skuric, V. Padois, N. Rezzoug and D. Daney. 'On-line feasible wrench polytope evaluation based on human musculoskeletal models: an iterative convex hull method'. In: *IEEE Robotics and Automation Letters* (2022). DOI: 10.1109/LRA.2022.3155374. URL: https://hal.inria.fr/hal-03369576.

12.2 Publications of the year

International journals

[7] B. Camblor, D. Daney, L. Joseph and J.-M. Salotti. 'Attention Sharing Handling Through Projection Capability Within Human-Robot Collaboration'. In: *International Journal of Social Robotics* (16th Feb. 2024). DOI: 10.1007/s12369-024-01101-9. URL: https://inria.hal.science/hal-04399124 (cit. on p. 16).

[8] É. Fournier-Aubret, A. Landry, B. Piras, D. Pellier, H. Fiorino, D. Daney and C. Jeoffrion. 'Proof of concept of a cobotic system in a constrained work environment'. In: *Applied Ergonomics* 125 (May 2025), p. 104472. DOI: 10.1016/j.apergo.2025.104472. URL: https://hal.science/hal-04926592.

[9] C. A. Rey Arias, W. Weekers, M. Morganti, V. Padois and A. Saccon. 'Refined Post-Impact Velocity Prediction for Torque-Controlled Flexible-Joint Robots'. In: *IEEE Robotics and Automation Letters* (2024). DOI: 10.1109/LRA.2024.3364469. URL: https://hal.science/hal-04148817.

[10] N. Rezzoug, A. Skuric, V. Padois and D. Daney. 'Simulation Study of the Upper-Limb Isometric Wrench Feasible Set With Glenohumeral Joint Constraints'. In: *Journal of Biomechanical Engineering* 147.2 (1st Feb. 2025), p. 024501. DOI: 10.1115/1.4067329. URL: https://hal.science/hal-04915107 (cit. on p. 6).

[11] J.-M. Salotti. 'Can humanity survive to a giant comet impact?' In: *Acta Astronautica* (Mar. 2024). DOI: 10.1016/j.actaastro.2024.03.050. URL: https://hal.science/hal-04530461.

[12] J.-m. Salotti and E. Suhir. 'Collaborative Robotics: Application of Delphi Method'. In: *Journal of Field Robotics* (27th Nov. 2024). DOI: 10.1002/rob.22477. URL: https://hal.science/hal-04868639 (cit. on p. 16).

International peer-reviewed conferences

[13] A.-M. Dahmani, D. Daney and F. Charpillet. 'Parametric trajectories and measurement error in inverse optimal control'. In: MMT Symposium 2024 - Mechanism and Machine Theory Symposium. Guimaraes, Portugal, 26th June 2024. URL: https://hal.science/hal-04718505 (cit. on p. 20).

[14] V. Fortineau, V. Padois and D. Daney. 'Prediction of pose errors implied by external forces applied on robots: towards a metric for the control of collaborative robots'. In: IEEE International Conference on Robotics and Automation - ICRA 2024. Yokohama, Japan, 14th May 2024. URL: https://inria.hal.science/hal-04410256.

[15] E. Landais, N. Rezzoug and V. Padois. 'Re-expression of manual expertise through semi-automatic control of a teleoperated system'. In: *Human Factors in Robots, Drones and Unmanned Systems; 15th International conference on Applied Human Factors and Ergonomics and the Affilated Conferences.* AHFE 2024 - 15th International Conference on Applied Human Factors and Ergonomics. Vol. 138. Nice, France, 2024. DOI: 10.54941/ahfe1005012. URL: https://hal.science/hal-04654144.

[16] M. Vulliez and O. Khatib. 'A New Compact Paired-Parallel Architecture for Haptic Transparency'. In: *Advances in Robot Kinematics 2024Springer Proceedings in Advanced Robotics.* AKR 2024 - 19th International Symposium on Advances in Robot Kinematics. Vol. 31. Springer Proceedings in Advanced Robotics. Ljubljana, Slovenia: Springer Nature Switzerland, 3rd July 2024, pp. 288–296. DOI: 10.1007/978-3-031-64057-5_33. URL: https://inria.hal.science/hal-04759634.

Conferences without proceedings

[17] A. Boulay, D. Daney and M. Vulliez. 'Ruling guidance an adaptive and dynamic haptic guide model'. In: *MMT Symposium BOOK OF ABSTRACTS.* MMT Symposium 2024 - Mechanism and Machine Theory Symposium. Guimaraes, Portugal, 26th June 2024, p.383–384. URL: https://inria.hal.science/hal-04776071.

[18] J. Savin, R. Bousigues, P. Maurice, V. Padois, N. Rezzoug and D. Daney. 'Motor variability in human-robot interaction during an assisted trajectory-tracking task: preliminary results from the MOVER experiment'. In: Humanoids 2024 workshop : Human movement modeling for Human-Robot interaction at Humanoids. Nancy, France, 22nd Nov. 2024. URL: https://hal.science/hal-04883474 (cit. on p. 17).

Doctoral dissertations and habilitation theses

[19] B. Camblor. 'Exploiting robot motion to improve situation awareness in human-robot collaboration'. Université de Bordeaux, 18th Apr. 2024. URL: https://theses.hal.science/tel-04573182 (cit. on p. 38).

[20] G. Laisné. 'Upper-limb force feasible set: theoretical foundations and musculoskeletal model reconstruction'. Université de Bordeaux, 17th Dec. 2024. URL: https://theses.hal.science/tel-04893926 (cit. on pp. 18, 38).

[21] E. Landais. 'Teleoperation for the remote expression of technical gestures : application to formulation in chemistry'. Université de Bordeaux, 6th Dec. 2024. URL: https://theses.hal.science/tel-04876966 (cit. on pp. 18, 38).

Reports & preprints

[22] V. Batto, L. de Matteis, T. Flayols, M. Vulliez and N. Mansard. *CLEO: Closed-Loop kinematics Evolutionary Optimization of bipedal structures*. 1st Oct. 2024. URL: https://laas.hal.science/hal-04717159 (cit. on p. 22).

[23] A. Boulay, B. Camblor, M. Vulliez and D. Daney. *A new unified and adaptive haptic guidance method, an exploratory user study*. 9th Oct. 2024. URL: https://inria.hal.science/hal-04727078 (cit. on p. 19).

[24] E. Jabbour, M. Vulliez, C. Preault and V. Padois. *A Model Predictive Control Approach To Blending In Shared Control*. 15th Sept. 2024. URL: https://hal.science/hal-04753213 (cit. on p. 20).

[25] G. de Mathelin de Papigny, F. Gassibe and V. Padois. *F-RRT: an Efficient Algorithm for Semi-Constrained Path Planning Problems*. 15th Sept. 2024. URL: https://hal.science/hal-04926299 (cit. on p. 23).

[26] L. de Matteis, V. Batto, J. Carpentier and N. Mansard. *Optimal Control of Walkers with Parallel Actuation*. 1st Oct. 2024. URL: https://hal.science/hal-04716938 (cit. on p. 22).

[27] A. Skuric, N. Torres Alberto, L. Joseph, V. Padois and D. Daney. *Online approach to near time-optimal task-space trajectory planning*. 15th May 2024. URL: https://inria.hal.science/hal-04576076 (cit. on p. 23).

12.3 Cited publications

[28] J. Bernon, E. Escriva and J. M. Schweitzer. *Agir sur la prévention durable des TMS*. Anact, 2011 (cit. on p. 5).

[29] F. Bunlon, J.-P. Gazeau, F. Colloud, P. J. Marshall and C. A. Bouquet. 'Joint action with a virtual robotic vs. human agent'. In: *Cognitive Systems Research* 52 (2018), pp. 816–827 (cit. on p. 7).

[30] J. Colombel, D. Daney and F. Charpillet. 'Holistic view of Inverse Optimal Control by introducing projections on singularity curves'. In: *2023 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE. 2023, pp. 12240–12246 (cit. on p. 20).

[31] P. Douillet. *Agir sur Prévenir les risques psychosociaux*. Anact, 2013 (cit. on p. 5).

[32] M. R. Endsley. 'Measurement of situation awareness in dynamic systems'. In: *Human factors* 37.1 (1995), pp. 65–84 (cit. on p. 6).

[33] M. O. Ernst and M. S. Banks. 'Humans integrate visual and haptic information in a statistically optimal fashion'. In: *Nature* 415.6870 (2002), pp. 429–433 (cit. on p. 6).

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