RESEARCH CENTRE

Inria Centre at the University of Bordeaux

IN PARTNERSHIP WITH:

Institut Polytechnique de Bordeaux

2023

ACTIVITY REPORT

Project-Team

AUCTUS

Robots for Humans at work

DOMAIN

Perception, Cognition and Interaction

THEME

Robotics and Smart environments

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Project-Team AUCTUS

Creation of the Project-Team: 2020 April 01

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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 the cognitive (HRI) and physical (pHRI) aspects of human-robot interaction. One of the main challenges is to characterize the task as well as 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 the way in which 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 of time. Similarly, kinematic or biomechanical analyses may tend to see humans as a high-performance machine 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, can actually be a good long-term strategy. These questions directly link motor and cognitive aspects that can be reflected in particular strategies such as the fatigue or the expertise (manual and cognitive). This approach has not been widely explored in robotics while it could determine the right criteria to adapt 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, expert in task analysis and psychology, and the robotician, 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, on the basis of 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 predictive 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 at analyzing:

- the physical and cognitive fragility of operators in order 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 [30, 32]. The aim is to translate these factors into metrics, optimality criteria or constraints which can be implemented in our methodologies 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 [44], REBA [36], LUBA [40], OWAS [39], ROSA [59],...). Until then, the use of more complex measurement systems was reserved for laboratories, particularly in biomechanical studies. The development of inexpensive sensors, such as IMUs (Inertial Measurement Units) or RGB-D cameras, makes it possible to consider a digitalized, and therefore objective, observation of the gesture, posture and more generally of human movement and at the same time collecting information on physiological states. Thanks to these sensors, which are more or less intrusive, observation systems can be permanently installed on production lines. This change of paradigm opens the door to longitudinal observations. It can be compared to the evolution of maintenance, which became predictive.

Ergonomic robotics has recently taken an interest in this new evaluation paradigm to adapt the robot behavior in order 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. The notation are compatible with an observation of the human operator through the eye of the ergonomist. In practice, such evaluations are inaccurate and subjective [62]. 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 at extending this approach to more reliable and comprehensive ergonomic metrics. The repetition of gestures, 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 [60]. However, this type of extrinsic method is not always suitable in the industrial context [43] where we place our research efforts.

Through these human analyses, the Auctus team aims at revising the use of collaborative robots in the workplace to vary the operator's environment and encourage more appropriate motor strategies. This approach relies on biomechanical studies of the intrinsic variability of the motor system allowed by the joint redundancy of the human body. This motor variability refers to the alternation of postures, movements and muscle activity observed in the individual to perform a requested task [60]. This variation leads to differences between the motor coordination used by each operator, and conveys the notion of motor strategy [37].

The cognitive dimension of ergonomics must also be addressed in our approach to reduce the mental workload and foster 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 [55] and, therefore, adjust the robot physical 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 particularly aim at adapting and refining known human cognitive models (multisensory perception [34], situation awareness [33]) to infer the influence of the task context and environment on the 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 and placement redundancy);
- the variability of the parameters, for example, physiological (set of operators), geometric (set of possible trajectories, postures, and placements of the operator), and static parameters (set of forces that the operator must produce with respect to the task and context);
- the uncertainties in the measurement and the model approximations.

The idea is to start from a description of redundant workspaces (geometric, static, dynamic...). We use set-theory approaches, based on interval analysis [61], [49], 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 [46]. 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.
- propose new ergonomic, biomechanical, robotic, and cognitive indices which 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 [50], to project human movements on the basis of the performance or ergonomic indices. Such a projection would offer new interpretations and enhance the analysis of human behaviors.

3.2 Operator / robot coupling

This research axis is at the frontier between humans and robots and focuses on optimal methods to couple together these two entities to perform joint activities. This raises questions which are directly related both 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 built in the 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[54] 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 [58]).

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 a 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 [31] or coordination mechanisms [48]. But the situation awareness of the operator is modified by the interaction with the robot [53]. Developing a joint mental model which accurately capture the human-robot interaction can later guide the design of relevant interaction modalities to improve the team 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 which 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 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 [47].

We are strongly confident that the notion of expertise is central to adjust 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 particular expertise and know-how in 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. Better understanding 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 clearly 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 a first avenue to predict possible changes in the expertise. It can be input to the controller to constraint the robot to naturally let the operator take the expert decisions.

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 [41]. 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 the humans to perform the considered task. On the basis of these analyses, the main challenge is to define a decision support tool for the choice of the robotic architecture and for 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 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 experiments and simulations. In parallel, an evaluation of the operator expertise and cognitive strategy is done by means of 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 current 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 dofs 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 for sets of cases. For example, it can be verified that, regardless of the bounded sets of simulated operator physiologies, 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, this integration of 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 into 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 at developing 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 sub-optimal 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 behaviour 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 [35] [45, 38], 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 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 [51, 52].

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 which would ensure discrete transitions from one task (and the associated assistance mode) to another based on an online

[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.

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 in 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 [42]. 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 on the basis of 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 to adapt the prediction horizon and the complexity of the corresponding model in order 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, in order 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 in 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.

6 Highlights of the year

This year, we would like to highlight several activities that support and enrich our research, while broadening our fundamental perspectives in our research areas. Firstly, we played an active part in bringing new advances in robotics to a wider public by participating in the events associated with the Robocup held in Bordeaux in July 2023. Our involvement extended to the organization of scientific events such as JNRH'23 and RosConfr'23. In addition, we showcased our scientific results of recent years through demonstrations specially designed for the general public, presented at the RoboCup.

This year also demonstrated our ability to carry out numerous experiments with human subjects, not only to collect the data essential for obtaining our results, but also to illustrate the interest of our contributions in cognitive science, human/robot interaction and biomechanics.

In addition, as part of the Robsys program at the University of Bordeaux, we took part in an in-depth study of our scientific partiques, particularly in robotics, from an ethical point of view. Led by Sylvie Michel from the Institut de recherche en gestion des organisations at the Université de Bordeaux, the study prompted us to question our ethical practices and achievements in the field of robotics. It has also prompted forward-looking reflections within the team on the implementation of robot ethics right from the design stage.

7 New software, platforms, open data

7.1 New software

7.1.1 pycapacity

Name: An efficient task-space capacity calculation package for robotics and biomechanics

Keywords: Computational geometry, Kinematics, Robotics, Biomechanics

Scientific Description: Python package pycapacity provides a set of tools for evaluating task space physical ability metrics for humans and robots, based on polytopes and ellipsoids. The aim of pycapacity is to provide a set of efficient tools for their evaluation in an easy to use framework that can be easily integrated with standard robotics and biomechanics libraries. The package implements several state of the art algorithms for polytope evaluation that bring many of the polytope metrics to the few milliseconds evaluation time, making it possible to use them in online and interactive applications.

The package can be easily interfaced with standard libraries for robotic manipulator rigid body simulation such as robotic-toolbox or pinocchio, as well as human musculoskeletal model biomechanics softwares opensim and biorbd. The package can also be used with the Robot Operating System (ROS).

The package additionally implements a set of visualization tools for polytopes and ellipsoids based on the Python package matplotlib intended for fast prototyping and quick and interactive visualization.

Functional Description: Pycapacity is a python package which provides a framework for the generic task-space capability calculation of robotic serial manipulators and human musculoskeletal models, based on the ellipsoid and polytope metrics. Additionally, the package also provides a set of generic polytope evaluation algorithms for standard polytope formulations, that can be used as a standalone library.

URL: https://github.com/auctus-team/pycapacity

Publications: hal-04316801, hal-03369576, hal-02993408

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7.1.2 PandaCapacityAR

Keywords: Unity 3D, Augmented reality, Robot Operating System (ROS), Polytopal meshes, Robotics

Functional Description: Unity HoloLens project for visualizing Panda robot's physical ability polytopes in Augmented Reality (AR). Complements the pycapacity package and interfaces with ROS architectures using the Unity Robotics Hub.

URL: https://gitlab.inria.fr/auctus-team/people/antunskuric/demos/polytope_ar_demo/pandacapacityar

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7.1.3 RobotReachSBA

Name: Sampling based robot reacable space approximation

Keywords: Robotics, Computational geometry, Triangulation

Functional Description: This package implements an efficient method for sampling-based reachable space approximation for robotic manipulators, given a certain horizon time of interest. The proposed method accounts for the robot's non-linear kinematics and allows the non-convex characterisation of the robot's reachable spaces.

URL: https://gitlab.inria.fr/auctus-team/people/antunskuric/example/reachable_workspace

Contact: Antun Skuric

7.1.4 Qontrol

Name: Quadratic Optimization coNTROL

Keywords: Robotics, Control, Optimisation

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.

Author: Lucas Joseph

Contact: Lucas Joseph

7.1.5 HYPO_MPC

Name: Hyper Paramter optimization for Model-Predictive Control-HYPOMPC

Keywords: Robotics, Telerobotics, Control, Optimal control, Shared control

Functional Description: The GitLab code, developed for the HYPO-MPC project, serves to enhance the performance of a given Model Predictive Controller based on user requirements. It is common to observe diverse behaviors generated by the controller, which are highly sensitive to coefficient parameters. These parameters often require extensive tuning, and adjusting one may inherently impact others.

The proposed code aims to streamline the tuning process, which is often quasi-impossible to achieve optimally manually. It provides users with options to select optimal parameters that can results in better accuracy, convergence speed, overshooting or computation time.

The code can be utilized by roboticists that are not expert or doesn't have the time to go through the tuning process of their controller.

URL: https://gitlab.inria.fr/auctus-team/people/eliojabbour/hyper-paramter-optimization-for-model-predictive-control-hypompc

Contact: Elio Jabbour

7.1.6 lmpcpp

Keyword: Collaborative robotics

Functional Description: Linear Model Predictive Controller used for research in robotics motion planning for safety, regarding this project: https://auctus-team.gitlabpages.inria.fr/publications/2022/icra23_mpc/

URL: https://auctus-team.gitlabpages.inria.fr/publications/2022/icra23_mpc/

Contact: Nicolas Torres Alberto

7.1.7 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.

Contact: Alexis Boulay

Participants: Alexis Boulay, Margot Vulliez, David Daney

7.1.8 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).

Contact: Alexis Boulay

Participants: Alexis Boulay, Margot Vulliez

7.1.9 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.

Contact: Margot Vulliez

Participants: Margot Vulliez, Alexis Boulay

7.1.10 Bioctus

Keywords: Biomechanics, Symbolic computation

Functional Description: Python module to create a kinematic chain actuated by cables and/or muscles. It allows the system jacobian computation as well as the cable wire matrix using symbolic elements defined through Sympy or Symengine. Symbolic computations are described via dual quaternions in order to create compact expressions. It is possible to desribe multiple biomechanical muscle models. At the moment, the Thelen Hill-type model is used as default. A sub-module allows automatic convertion of OpenSim musculosqueletal models into Bioctus.

URL: `https://gitlab.inria.fr/auctus-team/people/gautierlaisne/public/bioctus`

Author: Gautier Laisne

Contact: Gautier Laisne

7.2 New platforms

7.2.1 Ball catcher

Participants: Lucas Joseph.

An experimental setup was built for the RobotCup 2023 event held in Bordeaux in July. The setup exemplifies some of the state-of-the-art algorithms developed by the team in the field of robot control, specifically in Model Predictive Control, and also demonstrates the team's expertise in robotics. One of the goals of this setup was to be comprehensible to the scientific community, industrial professionals, and the general public. It involves a game in which the robot must catch a small ball thrown towards it in flight. A short video and a description can be found here.

This simple game requires the ability to detect the ball in real-time during its trajectory. This is accomplished using an OptiTrack sensor. Once the pose of the ball is determined, Model Predictive Control is employed to calculate the robot's trajectory to move towards the ball.

This setup was also used for other events and will be reused in the upcoming years.

7.2.2 ATROCE : Attention Tunneling and RObotic Collaboration Experiments

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

The platform consists in observing a human carrying out a task mobilizing his attention while a robot is working in its close environment. This platform will be used to study many cognitive aspects of a human carrying a task and how the robot can be used in such a situation.

A first set of experiment was conducted. The objective is to detect if the human is subject to an attentional tunneling effect and propose operating strategy for the robot to minimize the operator's entry into this incidental mental state. To monitor the human state, an eye tracking device and a heart rate monitoring device are used. While the human is doing a specific task, the robot must assemble several lego towers in a determined order. When the robot doesn't have the required lego to carry on its task, it must wait for the human to give it the correct lego block.

A second set of experiment is being developed to extend the study of cognitive aspects of a human carrying a task

7.2.3 MAXIFORCE: Maximal isometric force capacities measurement platform

Participants: Gautier Laisne, Lucas Joseph, Jean-Marc Salotti, Nasser Rezzoug, Pierre Garnault.

Understanding the human force capabilities is crucial for designing physical Human-Robot Interaction (pHRI) workspaces. This knowledge allows the robot to tailor its assistance, preventing the exceeding of force limits. However, these limits vary based on the operator's posture, muscle geometry, and biomechanical properties. The experimental arrangement outlined here is crafted to measure isometric maximal force capacities exerted in different directions by the right hand of a participant across various postures of the right upper limb.

The experimental procedure involves the placement of motion capture markers on the upper limb to capture posture, securing a shoulder belt to prevent translations while allowing rotations, utilizing a custom handle affixed to a 6D force-torque sensor positioned in front of the participant on a specialized table for handle displacement in all translations and rotations, and implementing a 3D interface to monitor the participant's posture and forces exerted on the handle. This interface provides visual feedback to ensure the desired upper limb posture.

This setup is employed to create a database of maximal isometric force capacities across four different postures for a dozen participants. The primary objective is to gather experimental force data for personalizing musculoskeletal model parameters to accurately replicate the forces exerted by each participant.

7.2.4 Trajectory Modulation Platform

Participants: Landais Erwann, Vincent Padois, Nasser Rezzoug.

A collaboration between Auctus and Solvay aims to enhance the skills of technicians engaged in visually classifying chemical compounds. The focus is on developing a teleoperation platform tailored to the task, allowing technicians to perform their duties from a remote location, ensuring their safety while leveraging their expertise for efficient task execution.

To address the challenge of ensuring a safe and responsive execution of the manual aspects of the task, the approach involves dividing movement control into two components: path control (defining spatial poses) and trajectory control associated with the path (managing speed and direction along the path). This allows users to partially guide robot movements, selecting a secure trajectory type and adjusting the real-time trajectory performed on this path.

A platform based on this concept was developed to assess its effectiveness in performing observation tasks compared to direct manipulation. The system underwent testing across a broad range of subjects.

7.2.5 Gimbal Platform

Participants: Landais Erwann, Vincent Padois, Nasser Rezzoug, Margot Vulliez.

Based on the findings from experiments conducted on the **Trajectory Modulation Platform** (see 7.2.4), a simplified manipulator arm has been devised specifically for the task of vial movements. The chosen design features a 3-degree-of-freedom arm, modeled after a gimbal, allowing the end-effector to execute only rotational movements across a broad range. The arm is designed to respect task-specific constraints, ensuring no collisions with its own components when holding the vial and avoiding obstruction of the camera based on the position of the robot elements. This design choice ensures an intuitive and responsive control of the platform's movements. Although the platform lacks translational movements, we anticipate it will deliver comparable execution times and success rates to those achieved in a live task.

Upon the completion of the development of this new platform, it will undergo additional testing with a group of subjects in an experiment.

7.2.6 Physical ability visualisation platform based on Augmented Reality tools

Participants: Antun Skuric, Claire Houziel, Margot Vulliez, Lucas Joseph, Vincent Padois, David Daney.

Auctus has conducted initial efforts in developing a platform for the interactive visualization of various metrics representing a robot's physical abilities to the operator, with a specific emphasis on their polytope representation. This visual and interactive information has the potential to offer real-time and interactive feedback to the operator regarding the robot's current state and physical capabilities. The overarching goal of the testing platform is to facilitate the comparison of different visualization modalities of this information, aiding in the understanding and evaluation of their effectiveness in diverse human-robot collaboration scenarios.

In this preliminary stage, the emphasis is placed on immersive visualization using Augmented Reality (AR) tools. More specifically, the initial setup revolves around a Microsoft HoloLens 2 device, chosen for its widespread use, off-the-shelf availability, and affordability.

A brief video showcasing the platform from the operator's perspective is publicly accessible via the provided link. The platform is open-source, and its code is available in the GitLab repository.

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, Axel Plantey–Veux.

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.This work was accepted for publication in a journal.

8.1.2 Adaptive task sharing

Participants: Jean-Marc Salotti.

Under the supervision of Jean-Marc Salotti, a team of 2 ENSC students, Thomas Faure and Hugo Decroux, implemented a task sharing experiment, in which a human operator and a robotic arm (Universal Robot UR3) had to pick and place tokens on a board. As the human operator had sometimes to be focused on another task, the robotic system was able to detect the unavoidability of the human (unexpected delays were observed) and adapted his sharing strategy to optimize the duration of the task. Related publications: [16].

8.1.3 Human perception of object properties

Participants: Louis Garcia, Margot Vulliez.

Better understanding human perception could help to develop feedback strategies that better inform a human operator during human-robot interaction, particularly in haptic teleoperation.

An experiment has been designed to study how humans perceive object physical properties of mass, stiffness, and viscosity, and how the perception of these properties can affect the others. The first experimental step identifies the perceptive threshold (JND) of each property individually, for a stimulus that is generated by a haptic device during a controlled back-and-forth user forearm motion. Two methodologies (constant and psychological) are implemented to extract the JND from collected data. The second experiment presents stimuli that simulate a combination of properties, to extract the impact or bias of the combination on each property perception.

This project, that was done in collaboration with the CeRCA (University of Poitiers), unfortunately stopped after the PhD student resignated for personal reasons, before the experiment was carried out.

8.2 Human Behavior Analysis

8.2.1 Holistic view of Inverse Optimal Control by introducing projections on singularity curves

Participants: Jessica Colombel, David Daney, François Charpillet.

Inverse Optimal Control (IOC) is a framework used in many fields, in particular robotics and human motion analysis. In this context, various solution methods have been proposed in the literature. This work introduces a new approach, Projected Inverse Optimal Control (PIOC), which offers a simple yet comprehensive view of inverse optimal control methods. In particular, we explain how uncertainties can be properly handled from our perspective. Thus, this work highlights how classical methods can be understood as trajectory projections in the solution space of the underlying direct optimal control (DOC) problem. This perspective makes it possible to examine projections other than classical methods, which can be fruitful for researchers in this field. Related publication: [15]

8.2.2 Improvement of the robustness of the projected inverse optimal control problem

Participants: Ahmed-Manaf Dahmani, Jessica Colombel, David Daney, François Charpillet.

A thorough exploration of the recent findings previously presented on Inverse Optimal Control (IOC) is currently underway as part of a thesis initiated in December 2023, following a master's internship. This study encompasses several crucial aspects. Firstly, we analyze the polynomial representation of trajectories, assessing its impact on the complexity and precision of the IOC problem. We examine and compare various types of projections onto singularity curves, proposing new methods to provide diverse characterizations of the uncertain IOC problem. Additionally, we explore strategies to mitigate high numerical errors, with a particular emphasis on normalizing cost functions.

8.2.3 Study of Motor Variability

Participants: Raphael Bousigues, David Daney, Vincent Padois.

The study of motor variability enables us to understand human strategies for carrying out a movement: it gives indications of an operator's state, particularly when interacting with a robot. To verify this hypothesis, we set up an experimental device that constrains the degrees of freedom of a human arm through a loop of physical wire to be followed and its observation by a motion capture system. This year, we had 18 subjects complete a course of curves and straight lines in a variety of conditions. The results are currently being processed.

8.2.4 Observing and recording information on an expert task

Participants: Erwann Landais, Vincent Padois, Nasser Rezzoug.

Within the framework of the study of the possible contributions of a semi-autonomous system for the realization of an expert task in the chemical industry, the question arose of identifying the components of the expertise expressed by the operator carrying out this task. To this end, several contacts were made with different operators, in the form of interviews and video recordings of demonstrations. Thanks to these interviews, the components of the expertise expressed by the operators could be highlighted (manual, visual and cognitive expertise), as well as a more general definition of the problematic linked to this task (manipulation of objects in the context of a visual classification task). This information opened up different lines of research concerning possible semi-autonomous assistances to help experts to carry out a task.

An experiment validated by INRIA's ethics committee was carried out to test the capabilities of the Trajectory Modulation Platform for performing a visual classification task. This experiment consisted in reading words printed on four white capsules (dimensions 6 x 12 mm) placed into cylindrical vials (dimensions 16 mm x 70 mm). Four randomly selected vials were tested by each variant. Firstly, users had to perform the task via direct handling, then under conditions secured by a protection barrier. Users were then invited to perform the task using different trajectory modulation variants (modulation and passive viewing of a pre-recorded video, modulation of the trajectory of a Franka-Emika Panda robot performing the task in real time in front of a monocular Logitech Brio 4K camera). After each trial of a variant, users evaluate different aspects of this variant (manual and visual performance, ease of use, acceptability of the interface) through a questionnaire. During the trials, various objective criteria are also measured (number and nature of interaction with the interface, time and degree of success in the task, physical posture of subjects to determine postural comfort using ergonomic metrics). This experiment was carried out with 37 subjects (age : 27±5, 20 females). The data recorded showed that the proportion of successes, as well as the subjects' perceptions of visual performance, comfort of use and acceptability of the interface, were similar and high for all the variants. This suggests that this task is indeed achievable via the proposed interface. However, data also showed that average task completion times when using the trajectory modulation variants were significantly higher than handling by hand variants, which implies that the proposed remote semi-automatic control procedure fails to achieve satisfactory performance regarding execution time. An interface allowing more reactive manipulation of the vial's movements seems necessary, and will be tested in a future experiment.

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

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

Derivative-free algorithms for force polytopes prediction 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 explores, 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. The solutions are then sampled from the positive areas. In average for all initial generations, the best polytope prediction comes from the solution found by the genetic algorithm for the polytope representation in 26 vertices. SRACOS tends to overfit more than genetic algorithms. Related publications: [9, 17]

Gathering of upper-limb maximal isometric force exertion associated with motion capture data An experimental setup has been designed to gather 26 maximal isometric force exertion at the right hand of a participant in 4 different postures. The setup ensures stability of the shoulder as well as minimizing the exertion of lower-limb muscles. Ten subjects participated to the experiment between October and December 2023, during two 3-hour sessions. The gathered data consists of force exertions acquired from a force-torque sensor as well as a scaled upper-limb musculoskeletal model with joint angles obtained via motion capture. It will be used as input for musculoskeletal model personalisation of muscle parameters.

Analytical expression for force polytope via Minkowski sums of superquadrics When measuring a subject's maximal force capacities in specific direction, we can suppose that we measure points at the surface of a polytope. The aim of this research was to express analytically these points, in order to parametrize a musculoskeletal model which would generate force polytopes fitting the measured points. The surface of a force polytope is described as the surface of torque zonotope intersected with the joint configuration's null space. Besides, the torque zonotope has great geometrical properties, thus it is possible to describe its surface via Minkowski sum of superquadrics (a generalization of ellipsoids which have simple analytic expression). First results were in 2D and lead to a smooth analytic expression

Novel description of force capacities: the force ovoid The set of isometric maximal forces of an operator can be geometrically treated through the study of force polytopes, usually described by its vertices. In static, these polytopes arise from intersecting the image of the jacobian transpose of a musculoskeletal model with the torque zonotope, which is the projection of the muscle tension space onto the torque space. However, computing such polytopes requires computational resources, even when approximating its vertices via the Iterative Convex Hull algorithm ([57]). A new approach suggests that when the muscle tension space is of a much higher dimensionality than the torque space, the produced torque zonotope resemble a smaller ellipsoid. An empiric formula has been established to express an ellipsoid dilation coefficient, which depends only on the tension space dimension and the mean feasible maximal tensions. This new representation of torque capacities led to a new force capacities representation created from the intersection of an ellipsoid and an affine space: an ovoid. This will be used as a new method for force capacities prediction, but also as a tool to better understand the impact of the muscle geometry and tensions to produce forces at the hand in the upper-limb.

Force polytope with constraints integration This work tackled two important points related to force polytope definition based on musculoskeletal models not taken into account in the available models. The first is the inherent instability of the gleno-humeral joint of the upper-limb prone to dislocation in case of important shear joint reaction force at this joint . The second one concerns the definition of the maximal force polytope taking into account movement dynamics and gravity. For both points, the original Iterative Convex Hull Method [57] was upgraded by modifying the vertex search linear programming problem of the ICHM with specific constraints. Simulation results attest the validity of these adaptations. Related publications:[27, 12]

Maximum upper-limb joint actuation: SimACT This work conducted with Jonathan Savin (INRS) aimed at providing an estimate of maximum joint torque actuation at the upper-limb elbow and shoulder. These data are needed for workplace ergonomic assessment in the framework of digital modeling tools (Delmia, Jack...). The approach taken consisted in using a musculoskeletal model and to infer the maximum joint actuation by resorting to polytopic representations. Related publications:[10]

8.3 Human Robot Interaction

8.3.1 A coupled view of the physical abilities of human-robot dyad for the online quantitative evaluation of assistance needs

Within the framework of Antun Skuric PhD thesis [22] (BPI Lichie Project 10.4), we pursued our work aiming at efficiently and accurately characterizing both human and robots physical abilites. Our contribution in this domain over the laster year is three-fold.

Online approach to near time-optimal task-space trajectory planning for collaborative robots Conforming to safety standards often imposes limitations on the performance and size of collaborative robots, making their applications only viable if fully exploiting their abilities. When it comes to planning for these robots' motions in human environments, there is often a trade-off to be made between the planning the optimal trajectories, which exploit their full movement potential, and the real-time responsiveness to the unexpected events in these dynamic and unstructured spaces. Traditional reactive trajectory planning methods, in order to be used online use simplified robot model, often over or underestimating robot's abilities. On the other hand, traditional methods that do exploit robot's abilities optimally have significant computational complexity and require being computed in-advance, not allowing for reactivity.

This method aims to bridge this gap, by introducing a method able to plan robot's trajectories that exploit its full motion abilities in real-time. The proposed online re-planning method in each step of trajectory execution 1) evaluates robot's movement ability in trajectory direction using an efficient tools from polytope algebra 2) calculates a time-optimal Trapezoidal acceleration profile (TAP) trajectory using the updated limits.

The method is compared against a state-of-the-art time-optimal joint-space planning method TOPP-RA and a classical reactive strategy, based on task-space TAP planning. Results show that the proposed method has a comparable trajectory execution time as TOPP-RA, while exploiting the robot's movement capacity better and having lower tracking error than the traditional TAP approach. A mockup experiment is presented where the proposed method is used for collaborative waste sorting using a Franka Emika Panda robot, showing the efficiency of the approach in a practical application.

Sampling-based non-convex approximation of the robot's reachable space This work introduces a preliminary work on the sampling-based reachable space approximation strategy within a horizon time of interest for robotic manipulators. This method builds on the previously introduced approach [56], and allows it to account for the robot's non-linear kinematics and allows the non-convex characterisation of the robot's reachable spaces. Therefore, the proposed method has a potential to provide an accurate characterisation of robot's reachable space. Robot's reachable space is valuable information both for the robot's motion planning and for the operator's understanding of the robot's physical abilities. However, at this stage this strategy lacks formal guarantees on its approximation accuracy, necessitating further research to enhance reliability and information quality conveyed to operators.

This sampling based method is publicly available as an open-source gitlab repository. Additionally, this algorithm will be a part of the upcoming release of the Pinocchio library confirming the interest of the robotics community in this approach.

8.3.2 Prediction of pose errors implied by external forces applied on robots: towards a metric for the control of collaborative robots

Participants: Vincent Fortineau, Vincent Padois, David Daney.

In [25], we tackle the question of quantifying the pose deviations of robots subject to external disturbance forces. While this question may not be central when considering large robots perfectly rejecting disturbances through high controller gains, it is an important factor to consider when considering collaborative settings where smaller robots may be deviated from their task because of unmodeled physical interactions. This is all the more true when considering human-robot collaboration where human capacities may fluctuate over time and have to be compensated by a proper adaptation of the robot control. To move forward in this direction, this works first derive a deviation prediction methodology and exemplifies it using three largely employed control approaches. The proposed prediction method is then validated using simulated and real robot experiments both in single and multiple robots cases. The obtained results constitute a stepping stone towards a quantitative metric for robot adapting their behaviour to human motor fluctuation.

8.3.3 Re-expression of manual expertise through semi-automatic control of a teleoperated system

Participants: Erwann Landais, Vincent Padois, Nasser Rezzoug.

An experiment validated by INRIA's ethics committee was carried out to test the capabilities of the Trajectory Modulation Platform for performing a visual classification task.

This experiment consisted in reading words printed on four white capsules (dimensions 6 x 12 mm) placed into cylindrical vials (dimensions 16 mm x 70 mm). Four randomly selected vials were tested by each variant. Firstly, users had to perform the task via direct handling, then under conditions secured by a protection barrier. Users were then invited to perform the task using different trajectory modulation variants (modulation and passive viewing of a pre-recorded video, modulation of the trajectory of a Franka-Emika Panda robot performing the task in real time in front of a monocular Logitech Brio 4K camera). After each trial of a variant, users evaluate different aspects of this variant (manual and visual performance, ease of use, acceptability of the interface) through a questionnaire. During the trials, various objective criteria are also measured (number and nature of interaction with the interface, time and degree of success in the task, physical posture of subjects to determine postural comfort using ergonomic metrics).

This experiment was carried out with 37 subjects (age : 27±5, 20 females). The data recorded showed that the proportion of successes, as well as the subjects' perceptions of visual performance, comfort of use and acceptability of the interface, were similar and high for all the variants. This suggests that this task is indeed achievable via the proposed interface. However, data also showed that average task completion times when using the trajectory modulation variants were significantly higher than handling by hand variants, which implies that the proposed remote semi-automatic control procedure fails to achieve satisfactory performance regarding execution time. An interface allowing more reactive manipulation of the vial's movements seems necessary, and will be tested in a future experiment.

8.3.4 Haptic guidance to assist human motion

Participants: Alexis Boulay, Margot Vulliez, David Daney.

This work is within the framework of the collaboration with the Farm3 company, which aims at developing a telerobotic system based on shared autonomy for the remote nurturing of plants in a controlled chamber. Performing remote tasks through the teleoperation system can be assisted through haptic guidance to increase performance, safety, and comfort of the user. Several axis were studied in this direction:

- State-of-the-art on haptic guidance: Also known as virtual fixture, active constraint or virtual guide, a haptic guidance is a virtual geometric constraint used to generate a force feedback that help the user to follow a given behaviour (task trajectory, safety area,...). The different definitions are strongly linked to the tasks studied, whether surgery, navigation or pick-and-place. They also are not limited to teleoperation but can be used on physical human-robot interaction or programing by demonstration. This task dependency highlights that there is no unified formalism to model haptic guidance. However, common computation methods can be identified for the generation of the guidance force, such as the use of spring-damper models (SD), the definition of potential fields (PF) or the establishment of restrictive zones with guiding tubes (GT).
- Definition of a generic haptic guidance expression, the ruling guidance (RG): the RG model is proposed to encompass common haptic guidances from the literature in a unique expression. It allows a continuous switch between these generic methods, through only few parameters, and an exploration of intermediate guidance states.
- Implementation of a modular teleoperation bilateral controller 7.1.8 with the active-constraint module 7.1.7 which integrates the standard haptic guidance (SD, PF, GT) and the proposed generic and parameterized ruling guidance (RG).

8.4 Robotics and control

8.4.1 Predictive Control of Collaborative Robots in Dynamic Contexts

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

Within the framework of Nicolas Torres PhD thesis (CIFRE Stellantis), we have continued exploring control architectures allowing for the online adaptation of robot motion when facing dynamically changing contexts where constraints and tasks to be achieved can evolve at all time. This led to several contributions on the theoretical [28] [23], experimental (cf. video here) and software 7.1.6 side of Model Predictive Control, formulated here in a linear fashion over $SE(3)$

8.4.2 Model Predictive Control for shared human-robot tasks

Participants: Elio Jabbour, Margot Vulliez, Vincent Padois.

Shared control emerges as a solution to improve conventional teleoperation through robotic assitance. It combines human and robot capabilities in a unified command, which could overcome limitations in both autonomous robots and fully teleoperated robot. We focus on shared control methods, and specifically:

- define two computation methods of the authority level (impact of each agent on the action), respectively based on the human activity and proximity to the task target. The resulting authority levels are, then, given by assigning fixed weights on both the activity or proximity factors, for each task's state of a pick-and-place scenario.
- formalize the equations of a shared-control paradigm that compute the desired robot motion (pose an twist) based on model predictive control (MPC). It optimizes and predicts the robot motion on a horizon, given the human and automation (planned automated trajectory) motion inputs and the authority levels, while respecting robot and human limits and environmental constraints. We are currently implementing and testing this MPC approach, and will compare it to conventional linear blending methods.
- propose a tool 7.1.5 to optimize the hyperparameters of a MPC framework thanks to a genetic algorithm (NSGA-II). It helps tuning the MPC parameters, such as the prediction time horizon, the velocity coefficient, and the control input weigth, based on objective functions that maximize the system-response rise time, minimize the steady-state error, and minimize the overshoot ratio, under a fixed computational-time constraint.

8.4.3 Criteria for evaluation of serial and parallel robot leg

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.

Several criteria to characterize the design of bipedal legs have been introduced. They aim to guide the design choices and could be implemented in a codesign approach. They reflect the leg's overall performances (ability to produce dynamic and accurate foot movements, absorb impacts, and lower the motor torques needed to stand up) and characterize the design's compactness.

We give the algorithmic formulations to evaluate these criteria beyond classical serial designs to account for any parallel mechanisms. To validate these formulations, we developed a library of open-source CAD models describing the main existing biped architectures. We compute and discuss the comparative performances of the architectures in the leg-model database. We hope this study can serve as a baseline to better design future biped robots.

Related publication: [14]

8.4.4 Optimization of a novel parallel leg architecture

Participants: Virgile Batto, Margot Vulliez.

Dynamic bipeds 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.

A new parallel leg architecture has been proposed and is currently optimized. This work is based on the software we developed for Closed Loop Architecture Optimisation Cleo. It also serves to improve the software. Cleo is an optimizer that takes as input the conceptual architecture design of the leg and returns a set of optimized solutions for the mechanical architecture by using a genetic algorithm.

The main objective of our design optimization is to generate the most dynamic leg possible with the given architecture, under different task requirements and geometric and kinematic constraints. We specifically minimize the effective inertia of the foot and maximize the impact mitigation factor of the leg. A prototype of the leg will be fully designed and built in the future to experimentally validate the optimized architecture.

8.4.5 Elasto-Geometric Calibration of a TALOS Humanoid Robot

Participants: David DaneyVincent Bonnet .

This result shows our work on robot calibration in collaboration with LAAS, CNRS. Elasto-geometric calibration of the whole body of humanoid robots is essential, particularly for their accurate control and simulation. We have proposed a new method which has been validated on a TALOS. It enables rapid, accurate whole-body calibration. The proposed approach has been cross-validated experimentally. Related publication: [7]

8.4.6 Solving semi-constrained end-effector path planning problems

Participants: Guillaume De Mathelin De Papigny, Vincent Padois.

Within the framework of the Plan de Relance with the SME Aerospline, we have mostly worked on proposing a compuationally efficient algorithm to solve semi-constrained end-effector path planning problems. Solving these problem is crucial to find motion solution for robots evolving in highly constrained environements while presenting some level of task redudancy.

8.4.7 Real time jogging respecting robot and task constraints

Participants: Sébastien Dignoire, Vincent Padois.

Auctus and Fuzzy Logic Robotics have been working together on the development of new methods for generating movement in industrial robotics thanks to optimization problem with constraints. These methods based on the resolution of quadratic programming problems allow to generate trajectories respecting the limits of the robot and the constraints of the task. For example, we implemented an online mouse jogging that allows the operator to control the robot in 6 dimensions exploiting the knowledge of the robot's state and its capacities.

9 Bilateral contracts and grants with industry

9.1 Airbus

Participants: David Daney, Vincent Padois, Antun Skuric.

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, see 10.4.

Project in a nutshell:

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

9.2 Stellantis

Participants: David Daney, Vincent Padois, Nicolas Torres.

The objective of this project is to work on the required principles to avoid the classic restrained static security zones, synthesizing a dynamic representation of the shared workspace to take advantage of state of the art control laws, allowing a fluid collaboration between human-robot. This dynamic synthesis requires knowledge of the robots state (geometric, cinematic and cognitive, such as fatigue, expertise and situation awareness), its tasks, capacities, state of humans that surround it and their tasks. Furthermore, it needs to achieve a formal and provable online algorithm that correctly estimates the state of the human and guarantee a safe shared workspace tackling ambitious scientific questions poorly addressed in literature.

Project in a nutshell:

- Consortium: AUCTUS@Inria, PSA Automobiles
- Funding: PSA Automobiles, ANRT (CIFRE)
- Duration: 2020–2023

9.3 Solvay

Participants: Vincent Padois, Nasser Rezzoug, Lucas Joseph, David Daney, Erwan Landais.

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, in 2021, we are participating in the Miels project (see 10.5) in order to cobotize a handling task for the mixing of chemicals that requires human gestural expertise. The difficulty is first to learn from the human and then to synthesize this expertise.

Project in a nutshell:

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

9.4 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

9.5 Aerospline

Participants: Guillaume De Mathelin de Papigny, Vincent Padois, Lucas Joseph.

Started in 2021, the partnership between AUCTUS and the robotics company Aerospline has two main objectives. On the one hand, the collaboration brings to Aeropline new scientific research knowledge in Robotics in order to develop new robotic methods and tools for their projects. On the other hand, it brings to AUCTUS elements for the formulation of new scientific problems.

Project in a nutshell:

- Consortium: AUCTUS@Inria, Aerospline
- Funding: Plan de Relance
- Duration: 2021-2023

9.6 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

Shared Haptics for Augmented Assistive Robot Expertise (SHAARE)

Participants: Kwang-Hyun Lee (Postdoc), Donghyeon Kim (PhD), Seong-Su Park (PhD), Jee-Hwan Ryu (Full Professor, IRiS@KAIST), Alexis Boulay, Vincent Padois, David Daney, Margot Vulliez.

A collaboration has been initiated with the IRiS lab at KAIST, to share our complementary methodological orientations in haptic shared control. We develop shared-control approaches that, either, better guide the human through adaptive haptic guidance, or adjust the robot behavior according to the human gestures. The IRiS lab develop virtual-fixture feedback from a task description given by the user. They also study machine learning strategies to transfer skills from the human to the robot in haptic teleoperation. The Auctus team focuses on the core problem of shared control under safety, human-centered, and task/environement constraints. They build upon model-based optimization problems to both generate the force feedback from virtual guidance and the robot command from the joint human inputs and robot skills.

These different approaches should together form a comprehensive shared haptic framework, where the human is guided toward optimal gestures and helped by the robot taking more autonomy on the task. This collaboration specifically aims at augmenting the robot assistive behavior in haptic teleoperation by simultaneously improving haptic guidance and transferring expert skills to the robot. The works focuse on: 1.Generating optimal virtual fixtures from the task semantics, user preferences, and robot/environment constraints; 2. Developing robust and adaptive robot assistive skills, modeled through task-oriented force-motion control primitives; 3.Transferring expert skills from the human operator to the robot during the interaction.

Project in a nutshell:

- Consortium: KAIST (IRiS lab, Daejeon, South Korea), AUCTUS@Inria
- Funding: None
- Duration: 2023 - ongoing

Design and control solutions for compact haptic device

Participants: Adrian Piedra (PhD), Mikael Jorda (Consultant Researcher), Oussama Khatib (Full Professor, AI lab@Stanford), Margot Vulliez.

This collaboration continues the works initiated in the past with the Stanford Robotics Lab, to develop a new compact haptic device. We are interested in improving some mechatronic design aspects to increase the device performance, such as the motors' drive controller or the gripper integration inside the handle. We together propose workspace mapping algorithms and control solutions for such a compact parallel architecture, that are tested within the sai2 simulation tool of the Stanford Robotics Lab and implemented on the developed prototype. Several visits to the Auctus team and at Stanford University have been done this year to boost collaborative progresses.

Project in a nutshell:

- Consortium: Stanford University (AI lab, Stanford Robotics, USA), AUCTUS@Inria
- Funding: None
- Duration: 2022 - ongoing

Improved Bearings-only Target Motion Analysis Using AI Tools (IMAnAI)

Participants: David Daney, , Fançois Charpillet.

The aim is to re-examine BOTMA (bearings-only target motion analysis) scenarios using new approaches from control and estimation theory or artificial intelligence.

Project in a nutshell:

- Consortium: Inria, IIT Delhi, Naval Group
- Funding: Inria, IIT Delhi, Naval Group
- Duration: 4 years

10.2 International research visitors

10.2.1 Visits of international scientists

Other international visits to the team

Participants: Mikael Jorda, Ludovic Righetti, Philip Long.

- Mikael Jorda

  Status Consultant Researcher

  Institution of origin Stanford Robotics lab, AI lab, Stanford University

  Country USA

  Dates 11th-13th September and 21st-23rd November 2023

  Context of the visit Technical works on motor control and cogging compensation for the co-developed haptic device. Simuations and tests of haptic controllers on our experimental platform.

  Mobility program/type of mobility Collaborative works on haptics, Stanford Robotics lab funding

- Ludovic Righetti

  Status Associate Professor

  Institution of origin NYU, Machines in Motion lab, New York

  Country USA

  Dates 23rd-24th October 2023

  Context of the visit PhD defense jury of Nicolas Torres, invited talk "Learning to optimize dynamic behaviors", collaboration with Vincent Padois

  Talk Learning to optimize dynamic behaviors video

  Mobility program/type of mobility PhD defense jury

- Philip Long

  Status Lecturer

  Institution of origin Atlantic Technological University, Galway

  Country Ireland

  Dates 6th-7th November 2023

  Context of the visit PhD defense jury of Antun Skuric, invited talk "Facilitating Human Robot Collaboration by making Robot's smarter", collaboration with Vincent Padois and Antun Skuric

  Talk Facilitating Human Robot Collaboration by making Robot's smarter

  Mobility program/type of mobility PhD defense jury

10.2.2 Visits to international teams

Research stays abroad

Participants: Margot Vulliez.

Visited institution: Stanford Robotics lab, AI lab, Stanford University

Country: USA

Dates: 5th-17th October 2023

Context of the visit: Transporting and setting-up in the lab experimental room the prototype of a haptic device we co-developed, planning future works in electronic and control to improve the current design.

Mobility program/type of mobility: Collaborative works on haptics, Stanford Robotics lab funding

10.3 European initiatives

10.3.1 Other european programs/initiatives

Impact Aware Robotics

Participants: Alessandro Saccon (Associate Professor, ME Dept, Dynamics and Control Group, Eindhoven University of Technology (TU/e)), Marco Morganti (Technical leader at Franka Robotics), Vincent Padois.

Aside the IAM European project, this informal scientific collaboration aims at improving impact models and the prediction of the behaviour of robots making desired or non desired impacts with their environment. This is foreseen as a necessry condition in order to better control these complex and essential transitions. This collaboration has led to several modelling, simulation and experimental campaigns among which the most recent one was led in collaboration with Franka Robotics, one of the European leader in collaborative robotics.

Project in a nutshell:

- Consortium: TU Eindhoven, AUCTUS@Inria, Franka Robotics
- Funding: None
- Duration: 2017 – ongoing

10.4 National initiatives

Parametrisation of robotic actions by demonstration

Participants: Julie Dumora, Olivier David (CEA LIST), Vincent Padois.

Intuitive programming is a field of research in robotics aimed at reducing time and expertise required for programming a robotic system. In this context, this project and the associated internship has focused on programming robotic actions based on semantic data. This semantic data symbolically describes objects of interest and their relationships in a language easily interpretable by a human. The goal is to create a repository of actions described semantically, which can be reused in a new context to program the robot. Actions are learned through demonstration, meaning they are performed directly with the robot. The pertinence of the proposed approach has been demonstrated experimentally on a set-up at CEA List in Bordeaux.

Project in a nutshell:

- Consortium: CEA LIST, AUCTUS@Inria
- Funding: None
- Duration: 2023

BPI LiChIE

Participants: Antun Skuric, 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 - 2023
- Researchers involved: Antun Skuric (PhD Student), Vincent Padois (thesis advisor) and David Daney (thesis advisor)

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 (Postdoc), Jean-Pierre Gazeau (Research Engineer CNRS, RoBioSS@Pprime), Cécile Scotto (Interactions@CeRCA), Elio Jabbour, Vincent Padois, Margot Vulliez.

A young-researcher ANR grant was obtained in 2021 to start a collaborative project 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

LAAS-AUCTUS collaborations

Participants: Thomas Flayols (Research Engineer CNRS), Nicolas Mansard (Senior Researcher CNRS), 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:

- **Humanoid robot calibration:** A collaboration on problems of elasto-geometric calibration of humanoid robots has been carried out (see 8.4.5).
- **Inverse Optimal Control:** A collaboration on Inverse Optimal Control problem has started in pursuit of the results obtained in 8.2.1.
- **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). First results of this PhD project are presented in 8.4.3 8.4.4.

Project in a nutshell:

- Consortium: AUCTUS@Inria, GEPETTO@LAAS (CNRS)
- Funding: None
- Duration: 2021 - ongoing

LORIA-AUCTUS collaborations

Participants: Pauline Maurice (Researcher CNRS), Jessica Colombel (Postdoc), François Charpillet (Senior Researcher Inria, LARSEN@LORIA), Jonathan Savin (Engineer, INRS), Ahmed-Manaf Dahmani, Raphael Bousigues, David Daney, Vincent Padois, Nasser Rezoug.

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 8.2.1) and the study of motor variability in collaboration with INRS and Institut P' (see 8.2.3). 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

Participants: Caroline Pascal.

- Caroline Pascal

  Status PhD student

  Institution of origin ENSTA

  Dates 20 November to 1st December November 2023

  Context of the visit Experimental work on the calibration of serial robots for high accuracy applications

  Talk Robotized measurements for geometric and acoustic characterization of unknown structures video

  Mobility program/type of mobility R4 mobilty program

10.5 Regional initiatives

Robsys – Robustness of Autonomous Systems

Participants: Auctus as a whole .

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 robus 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@Inria, MNEMOSYNE@Inria), 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

AAPR Perception-HRI

Participants: Cécile Scotto (Interactions@CeRCA), Louis Garcia, 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 - 2025

Auctus@La-Coupole

Participants: Marjorie Paillet, Romain Pacanowski (Manao), Lucas Joseph (SED), Vincent Padois.

La Coupole is a research projet led by Romain Pacanowski (Manano) aiming at providing a robotized set-up for the digitalization of the visual appearance of historical artefacts. Given the expertise of the Auctus team in robotics, an on-going informal collaboration between the two teams exists since 2022. The adressed topics range from: control software architecture, motion planning, hardware adaptation and design, robot calibration,...

Project in a nutshell:

- Consortium: AUCTUS@Inria, MANAO@Inria
- Funding: None
- Duration: 2022 - ongoing

R4 – Regional Network on Robotics Research

Participants: Auctus as a whole .

R4 is a regional robotics network involving 12 research entities in the region of Nouvelle-Aquitaine, France. The objective of the network is to boost research activities, mainly through a weekly working group.

Project in a nutshell:

- Consortium: CRONE (IMS - University of Bordeaux / Bordeaux INP / CNRS), RHOBAN@LaBRI (UB,Bordeaux INP,CNRS), PROGRESS@LaBRI (UB,Bordeaux INP,CNRS), AUCTUS@Inria, FLOWERS@Inria, MNEMOSYNE@Inria, ESTIA-Recherche (ESTIA Bidart), LIUPPA (University of Pau and Pays de L'Adour), REMIX (XLIM - University of Limoges), ROBIOSS (Institut PPRIME - University of Poitiers), L3i (University of La Rochelle), I2M (ENSAM), ONERA
- Funding: Région Nouvelle-Aquitaine
- Duration: 2020 - ongoing

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair

- Nasser Rezzoug Scientific chair of the 48th congress of the French speaking Society of Biomechanics, Grenoble, 25-27 october 2023.
- Vincent Padois Local chair the 2023 Journées Nationales de la Robotique Humanoïde, Bordeaux, 5th-7th July 2023

Member of the organizing committees

- David Daney, Benjamin Camblor and Jean-Marc Salotti organized the workshop Variability and Adaptability in Human-Cobot Collaboration, Bordeaux (ENSC), December 2023.
- Lucas Joseph was part of the organization comitee of the ROSConfr, Bordeaux, July 4-5 2023.
- Antun Skuric was part of the organization comitee of the JNRH, Bordeaux, July 5-7 2023.

11.1.2 Scientific events: selection

Member of the conference program committees

- Lucas Joseph was part of the scientific comitee of the ROSConfr, Bordeaux, July 4-5 2023.

Reviewer List of conferences for which Auctus members have review activities :

- Robotics: 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2023 IEEE International Conference on Robotics and Automation (ICRA), ACM/IEEE Human Robot Interaction (HRI 2024)
- Biomechanics: 2023 IEEE International Conference of the Engineering in Medicine and Biology Society (EMBS), 48th congress of the french speaking Society of Biomechanics

11.1.3 Journal

Member of the editorial boards

- Nasser Rezzoug Journal of Biomechanics as representative of the french speaking Society of Biomechanics
- Vincent Padois Associate Editor at ICRA and IROS

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

- Robotics: IEEE Robotics and Automation Letters, Mechanism and Machine Theory, IEEE Transactions on Robotics, IEEE Transactions on Haptics, Journal of intelligent manufacturing, International Journal of Social Robotics
- Biomechanics: Journal of Biomechanics, Sports Biomechanics, Medical Engineering and Physics
- Software: Journal of Open Source Software
- Space: Microgravity Science and Technology, Journal of Aerospace Information Systems, Acta Astronautica, Journal of Space Safety Engineering, QEIOS
- Others: Frontiers Neurosciences,

11.1.4 Invited talks

- Virgile Batto - “A computational approach for optimizing the design of biped robots”, at R4, November 2023.
- Alexis Boulay - "A haptic guidance generic approach", JJCR 2023 - Journée des Jeunes Chercheurs en Robotique, Oct 2023, Moliets et Maâ, France.
- Benjmain Camblor - “Managing attention through projection in human-robot collaboration”. Workshop Variability and Adaptability in Human-Cobot Collaboration, Bordeaux (ENSC), December 2023.
- Benjmain Camblor - “Situation awareness and attention sharing in human-robot interaction”. Presentation for Pacbot project, Grenoble (LIG) May 2023.
- Benjmain Camblor - “Guide to conducting an empirical study of human-robot interaction”. Auctus seminar, Bordeaux, March 2023.
- David Daney - "Human Posture Analysis for Human-robot Interaction", Workshop IIT Delhi, October 2023.
- David Daney - "Cobotics for laboratories", Digital Days at Solvay, November 2023.
- David Daney - "Industrial robotics, challenges, work in progress and needs", Workshop Best, December, 2023.
- Elio Jabbour - "Haptic shared control in human-robot collaboration", JJCR 2023 - Journée des Jeunes Chercheurs en Robotique, Oct 2023, Moliets et Maâ, France.
- Gautier Laisne - “Musculoskeletal model identification using force polytopes”, at Institut Pprime (Poitiers), March 2023, Talence.
- Antun Skuric - “Unifying view of physical ability metrics for humans, robots and their collaboration”, at R4, June 2023.
- Antun Skuric - “Unifying view of physical ability metrics for humans, robots and their collaboration”, at Biomimetics lab at the MIT, May 2023.
- Antun Skuric - “Approximating robot reachable space using convex polytopes”, at JNRH, July 2023.
- Nicolas Torres - “Model Predictive Control for robots adapting their task space motion online”, at R4, June 2023.
- Nicolas Torres - “High-frequency Model Predictive Control for Online task-space trajectory replanning”, at PosterDay Stellantis, September 2023.
- Margot Vulliez - “Task, Hardware, and control: challenges in legged-robot design”, at JNRH, Bordeaux, July 2023
- Vincent Padois - "One or two vague (and somewhat pessimistic) ideas for a last minute presentation on robot control to open a Sunday lunch discussion" at Robotics Bordeaux Open Workshop (ROBOW), Rhoban, Université de Bordeaux, Gradignan, Feb 2023
- Vincent Padois - "Collaborative Robotics: Myths, Legends and Facts or a few small steps towards human-robot collaboration" at French-Italian Workshop on Robotics 4.0 for factories of the future, Cité des Sciences, Paris, Jun 2023

11.1.5 Leadership within the scientific community

- Nasser Rezzoug is vice-President of the french speaking Society of Biomechanics.

11.1.6 Scientific expertise

David Daney was a reviewer for "Défis Clés" of the regional initiative "Robotique centrée sur l'humain" of the Occitanie region.

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.

The Auctus team is involved in the European Digital Innovation Hub DIHNAMIC. Within this framework, David Daney has carried out several industrial expertise missions, notably for "retour à la plage" and "Safran Helicopter Engines".

11.1.7 Research administration

- Virgile Batto is Doctoral students' representative at the EdSys doctoral school
- David Daney is the principal investigator of ANR Pacbot
- 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.
- Vincent Padois is since september 2022 head of the "Commission des Développements Technologiques" for the Inria Bordeaux research center.
- Jean-Marc Salotti is in charge of international relations at ENSC
- Jean-Marc Salotti is member of the Commission des Emplois de Recherche de Inria Bordeaux Sud-Ouest (CER-BSO). He reviewed several PhD, Post-doc and "délégation" Applications in preparation of deliberations.
- Margot Vulliez is the principal investigator of the ANR ASAP-HRC and AAPR Perception-HRI projects.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

- Licence: Virgile Batto, Robotics, 5h eqTD, L2, BUT GE2I, Toulouse, France.
- Master: Alexis Boulay, Projet Informatique Individuel, 6h éqTD, M1, Ensc.
- Master: Alexis Boulay, Interactions humaines-robots et architectures cognitives, 10.6h éqTD, M2, Ensc.
- Master: Alexis Boulay, Introduction à ROS 21.75h éqTD, M2, Enseirb.
- Master: Benjamin Camblor, Fonction cognitives en situation et Handicap, 11.25 éqTD, M1 (S7), Master de Sciences cognitives et Ergonomie, Université de Bordeaux, France.
- Licence : Benjamin Camblor, TER (supervision of projects), 10h éqTD, L3 (S6), Licence MIASHS, Université de Bordeaux, France.
- Licence : Benjamin Camblor, Fonction exécutives, 10.50h éqTD, L2 (S4), Licence MIASHS, 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, 3h eqTD, M2, Enseirb/Ensc, Bordeaux INP, France.
- Master: Guillaume de Mathelin, IA & Robotics: Planning,10h, M2 , Enseirb/ENSC, Bordeaux INP, France.
- Master: Sébastien Dignoire, Projets de Robotique Mobile et introduction ROS, 40h éqTD, M2, Polytech Sorbonne Université, Paris, 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, 10h 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: Antun Skuric, Mathématiques et Informatique (Intermédiaire), 15h éq TD, M1, ENSAM Bordeaux, Arts et Métiers ParisTech, France.
- Master: Antun Skuric, Mathématiques et Informatique (Avancé), 15h éq TD, M2, ENSAM Bordeaux, Arts et Métiers ParisTech, 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, 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.

11.2.2 School

- Alexis Boulay participated in the winter school Agimus project on robotics at Banyuls-sur-Mer, December 2023.
- Elio Jabbour participated in the winter school Agimus project on robotics at Banyuls-sur-Mer, December 2023.

11.2.3 Supervision

PhD

- PhD in progress: Benjamin Camblor, Situation Awareness in Collaborative Robotics, funding: ANR Pacbot, January 2020 - Jean-Marc Salotti .
- PhD in progress: Raphaël Bousigues (Thèse ED SPI, Bordeaux / INRS-Inria), "Motor variability in human-robot collaboration", December 2020 – Pauline Maurice, Vincent Padois , David Daney and Jonathan Savin.
- PhD in progress: Erwann Landais (MIELS project, Région NA), "Approche robotique pour la formulation de nouveaux solvants",Sept 2021 –, Vincent Padois and Nasser Rezzoug.
- PhD in progress: Gautier Laisné (Inria), "Musculoskeletal models and data driven learning for personalized human force capacities evaluation", October 2021 -, Nasser Rezzoug and Jean-Marc Salotti.
- 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.
- PhD in progress: 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.
- PhD in progress: Elio Jabbour (Inria), "Shared-autonomy control for improving Human-Robot collaborarion in haptic teleoperation", funding: ANR ASAP-HRC, October 2022-, Margot Vulliez , Jean-Pierre Gazeau (Pprime Institute CNRS) and Vincent Padois.
- PhD in progress: Ahmed-Manaf Dahmani (Inria), "Robust inverse optimal control for human motion analysis", funding: Inria, December 2023-, David Daney, François Charpillet (Inria Nancy).
- PhD in progress: 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.

PhD passed

- PhD passed: Pierre Laguillaumie (Université de Poitiers), "Pierre Laguillaumie "Methodology for the implementation of a new generation of collaborative robots taking into account the safety and the biomechanical comfort of the operator in a work situation", November 2018 / September 2023, Jean-Pierre Gazeau and Vincent Padois.

- PhD passed: Nicolas Torres (Thèse ED SPI, Bordeaux / CIFRE PSA), “Synthesis and dynamic analysis of the shared workspace for safety in collaborative robotics”, April 2020 / October 2023, Vincent Padois and David Daney.
- PhD passed: Antun Skuric (Thèse ED SPI, Bordeaux / Financement projet Lichie Airbus), “A coupled view of the physical abilities of human-robot dyad for the online quantitative evaluation of assistance needs”, July 2020 / November 2023, Vincent Padois and David Daney.

Master

- Master 2: Ahmed-Manaf Dahmani (Robotics), "Robust inverse optimal control for human motion analysis", April-Sept 2023, David Daney, François Charpillet (Inria Nancy)
- Master 2: Pierre Garnault (Robotics), “Modélisation et mesure des capacités de forces du membres supérieur à l’aide d’un modèle musculosquelettique”, February - Aug 2023, Gautier Laisné, Jean-Marc Salotti, and Nasser Rezzoug
- Master 2: Victor Dhédin (Robotics), "Parametrisation of robotic actions by demonstration", 2023, Julie Dumora (CEA), Olivier David (CEA), Vincent Padois
- Master 1: Axel Plantey–veux, (Sciences cognitives et Ergonomie) “cobotic and human-robot interaction”, April 2023 - May 2023, Jean-Marc Salotti and Benjamin Camblor
- Master 1: Claire Houziel (Mechatronics and Rehabilitation, Sorbonne Université), "Improving workspace sharing in collaborative Robotics", May-Jun 2023, Vincent Padois, Antun Skuric, Margot Vulliez, Lucas Joseph

11.2.4 Juries

PhD

- David Daney
  - Maxime Selingue, Reviewer, "Amélioration de la précision de structures sérielles poly-articulées par des méthodes d’apprentissage automatique économes en données", HESAM Université, ENSAM Lille, Richard Béarée, Adel Olabi et Stéphane Thiery, 22/12/2023.
- Nasser Rezzoug
  - Brenda Elizabeth Olivas Padilla, Reviewer, "Deep state-space modeling for explainable representation, analysis, and forecasting of professional human body dynamics in dexterity understanding and computational ergonomics", Ecole des Mines de Paris, Université PSL, 19/03/2023.
  - Théo Rouvier, Reviewer, "Approche biomécanique pour quantifier l’accessibilité en fauteuil roulant manuel", ENSAM Paris, HESAM Université, 30/06/2023.
  - Nicolas de l’Escalopier, Reviewer, "Évaluation par InertialoLocographie de l’impact de la chirurgie du Pied Varus Équin Spastique sur la démarche des patients hémiplégiques après Accident Vasculaire Cérébral", Centre Borelli, Université Paris Cité, 8/12/2023.
  - Ajer Srihi, Examiner, "Stratégies de Stabilité en Position Assise chez les Personnes Vivant avec une Lésion de la Moelle Épinière : de l’estimation utilisant des modèles descripteurs quasi-LPV à la validation expérimentale", LAMIH (CNRS), Université Polytechnique des Hauts de France, 21/12/2023.
  - François Loisel, Reviewer, "Analyse cinématique et biomécanique de la main et du poignet par modélisation personnalisée. Effet de lésions et d’instrumentations", ENSAM Paris, HESAM Université, 22/12/2023.
- Margot Vulliez

  - Fanny Risbourg, Examiner, "Contributions à la commande prédictive pour la marche des quadrupèdes sur terrain 3D", LAAS CNRS, Université de Toulouse, 31/01/2023.

- Vincent Padois
  - Effie Segas, Reviewer, "Contrôle biomimétique de prothèses à partir des mouvements résiduels et d'informations contextuelles", INCIA, Université de Bordeaux / CNRS, 24/03/2023
  - Amit Parag, Reviewer, "A Supervised Formulation of Reinforcement Learning: toward Super-linear Convergence Properties", LAAS CNRS, Université de Toulouse, 20/04/2023
  - Mago Jesus, Reviewer, "Mechanical Design and Control of a Robotic Holder for Minimally Invasive Surgery", ISIR CNRS/Inserm, Sorbonne Université, 15/05/2023
  - Morgan Langard, Examiner, "Robot humanoïde bioinspiré - Conception et expérimentation", LARIS, Université d'Angers, 18/12/2023
  - Étienne Ménager, Reviewer, "Exploring state descriptions and soft robot simulations for learning and control", Inria, Université de Lille, 21/12/2023

HDR Vincent Padois: Mourade Benoussaad, Reviewer, "Towards Physical Human Robot Collaboration : Challenges and Perspectives", Université de Toulouse, 28/11/2023

Recruitment

- David Daney participated in recruitment jury MCF, IMT Altantique, 16/05/2023
- Nasser Rezzoug participated in recruitment jury MCF, Université de Poitiers, Institut Pprime, 16/05/2023
- Margot Vulliez participated in recruitment jury MCF, Université de Montpellier, LIRMM, 12/05/2023

Award

- David Daney participated as Jury member to the "Prix de thèse" 2022 of the "GDR Robotique".
- Nasser Rezzoug participated as Jury member to the senior researcher award "Prix Christian Oddou" 2023 of the french speaking international Society of Biomechanics.

11.3 Popularization

11.3.1 Articles and contents

- Gautier Laisné and Antun Skuric: Podcast speakers for "Désassemblons le numérique", Inria de l'Université de Bordeaux, June 2023, Talence.
- Vincent Padois : podcast serie "Une minute avec ..." link here, Centre Inria de l'Université de Bordeaux, 2023, Talence.
- Lucas Joseph : podcast serie "Une minute avec ..." link here, Centre Inria de l'Université de Bordeaux, 2023, Talence.

11.3.2 Education

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

- Alexis Boulay, Lycée Maryse Condé, Sarcelles, December 2023
- Vincent Padois, Lycée Stendhal, Aiguillon (47), December 2023
- Vincent Padois, Fête de la Science, Inria Talence, October 2023

Classe transplantée Robot - CapScience Presentation of robotic research to primary school students

- Margot Vulliez, CapScience, Côté Sciences Air&Espace, Mérignac, April 2023.
- David Daney, CapScience, Côté Sciences Air&Espace, Mérignac, May 2023.
- Lucas Joseph, CapScience, Côté Sciences, Floirac October 2023.
- Margot Vulliez, CapScience, Côté Sciences Floirac, October 2023.
- Vincent Padois, Inria, École Jean Jaurès de Villenave d'Ornon, March 2023.

11.3.3 Event

- Alexis Boulay, Elio Jabbour, Lucas Joseph, Vincent Padois, **"Fête de la science !"**, Running a stand demonstrating collaborative robotics algorithms, October 2023.
- Vincent Padois, **"Fête de la science ! Le Bureau des Enquêtes"**, October 2023.
- Nasser Rezzoug: 2023 french **"National Biomechanics Day"** event at the "Espace Mendès France" (Poitiers), 5 april 2023. Various workshops were offered to college students and the general public to present biomechanics. Evening seminars on biomechanics were offered to the general public. Attendance: 80 people
- Alexis Boulay, Elio Jabbour, Lucas Joseph, Benjamin Camblor, Gautier Laisné, Claire Houziel, Margot Vulliez, Vincent Padois, David Daney participated in the **RoboCup** that took place from July 4th to July 10th, 2023. We organized several scientific events (JNRH, RosConfr), participated in round-table discussions and conducted a public demonstration showcasing our scientific results.

11.3.4 Interventions

- David Daney, Gautier Laisné, Antun Skuric - **"Unithé ou Café"**, Inria de l'Université de Bordeaux, April, Talence, 2023.
- Lucas Joseph - **"Midi de la bidouille. Hugo"**. INRIA, Novembre, Bordeaux, 2023.
- Margot Vulliez - invited to a public round-table at **Robocup'23**, and **"Robots and Science-Fiction"** by Hypermondes, Bordeaux, July 2023.

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.

[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.

[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] V. Bonnet, J. Mirabel, D. Daney, F. Lamiraux, M. Gautier and O. Stasse. 'Practical whole-body elasto-geometric calibration of a humanoid robot: Application to the TALOS robot'. In: *Robotics and Autonomous Systems* 164 (June 2023), p. 104365. DOI: 10.1016/j.robot.2023.104365. URL: https://hal.science/hal-04222944.

[8] V. Fortineau, I. A. Siegler, M. Makarov and P. Rodriguez-Ayerbe. 'Human arm endpoint-impedance in rhythmic human-robot interaction exhibits cyclic variations'. In: *PLoS ONE* 18.12 (2023), e0295640. DOI: 10.1371/journal.pone.0295640. URL: https://hal.science/hal-04346387.

[9] G. Laisné, J.-M. Salotti and N. Rezzoug. 'Genetic algorithms for force polytopes prediction'. In: *Computer Methods in Biomechanics and Biomedical Engineering* 26.sup1 (24th Oct. 2023), pp. 218–220. DOI: 10.1080/10255842.2023.2246304. URL: https://hal.science/hal-04396514.

[10] J. Savin, D. Haering, N. Rezzoug and C. Pontonnier. 'Simulation of maximum isometric and isokinetic elbow actuation torques based on zonotopes'. In: *Computer Methods in Biomechanics and Biomedical Engineering* (2023), pp. 1–2. URL: https://inria.hal.science/hal-04140099.

[11] 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.

[12] A. Skuric, N. Rezzoug, D. Daney and V. Padois. 'Dynamics aware Cartesian wrench polytope estimation based on human musculoskeletal models'. In: *Computer Methods in Biomechanics and Biomedical Engineering* 26.sup1 (2023), S210–S212. DOI: 10.1080/10255842.2023.2246304. URL: https://inria.hal.science/hal-04190087.

Invited conferences

[13] M. Desvergnes, N. Louveton, C. Scotto Di Cesare, K. Belhassein, M. Vulliez, P. Laguillaumie, C. Préault, J. Pylouster, J.-P. Gazeau and L. Le Bigot. 'Développement d'un scénario de maintenance industriel, écologique et reproductible pour l'évaluation ergonomique des interfaces humain-machine et de la charge mentale'. In: *ERGO'IA 2023, October 10–13, 2023, Bidart, France.* ERGO'IA 2023 - "L'avenir de l'humain dans les systèmes sociotechniques du futur". Biarritz, France, 2023. URL: https://hal.science/hal-04405063.

International peer-reviewed conferences

[14] V. Batto, T. Flayols, N. Mansard and M. Vulliez. 'Comparative metrics of advanced serial/parallel biped design and characterization of the main contemporary architectures'. In: IEEE-RAS International Conference on Humanoid Robots 2023. Austin (Texas), United States, 12th Dec. 2023. URL: https://hal.science/hal-04191553.

[15] J. Colombel, D. Daney and F. Charpillet. 'Holistic view of Inverse Optimal Control by introducing projections on singularity curves'. In: *IEEE International Conference on Robotics and Automation (ICRA).* 2023 IEEE International Conference on Robotics and Automation (ICRA). London, United Kingdom: IEEE, 29th May 2023, pp. 12240–12246. DOI: 10.1109/ICRA48891.2023.10161163. URL: https://hal.science/hal-03926294.

[16] T. Faure, H. Decroux and J.-M. Salotti. 'Adaptive Task Sharing in Collaboarative Robotics'. In: *Proceedings of the ICRA23 workshop: Cognitive Modeling in Robot Learning for Human Robot-Interactions*. ICRA23 - Workshop: Cognitive Modeling in Robot Learning for Human Robot-Interactions. Londres, United Kingdom, 2nd June 2023, https://sites.google.com/view/cognitive-modeling-icra2023\bibrangedashws/contributions. URL: https://hal.science/hal-04133473.

[17] G. Laisné, J.-M. Salotti and N. Rezzoug. 'Derivative-Free Optimization Approaches for Force Polytopes Prediction'. In: ESANN 2023 - European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning. Bruges, Belgium, 2023, pp. 339–344. DOI: 10.14428/esann/2023.ES2023-122. URL: https://hal.science/hal-04330766.

[18] J.-M. Salotti. 'Long term shelters to avoid humanity extinction'. In: *IAA Website*. PDC 2023 - 8th IAA Planetary Defense Conference. Vienna, Austria, Apr. 2023. URL: https://hal.science/hal-04402965.

[19] J.-M. Salotti. 'Surface Energy Production Issues for the Refueling of Starships'. In: *Proceedings of the 74th IAC - IAF Website*. IAC 2023 - 74th International Astronautical Congress. Baku, Azerbaijan, Oct. 2023. URL: https://hal.science/hal-04402950.

National peer-reviewed Conferences

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Doctoral dissertations and habilitation theses

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