Activity Report 2018

Team AUCTUS

Augmenting human comfort in the factory using cobots

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions).

RESEARCH CENTER
Bordeaux - Sud-Ouest

THEME
Robotics and Smart environments

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Team AUCTUS

Creation of the Team: 2017 January 01

Keywords:

Computer Science and Digital Science:

A2.1.5. - Constraint programming
A5.1.1. - Engineering of interactive systems
A5.1.2. - Evaluation of interactive systems
A5.1.7. - Multimodal interfaces
A5.4.4. - 3D and spatio-temporal reconstruction
A5.4.5. - Object tracking and motion analysis
A5.5.1. - Geometrical modeling
A5.10.1. - Design
A5.10.2. - Perception
A5.10.4. - Robot control
A5.10.5. - Robot interaction (with the environment, humans, other robots)
A5.10.8. - Cognitive robotics and systems
A5.11.1. - Human activity analysis and recognition
A6.4.6. - Optimal control
A8.3. - Geometry, Topology
A8.10. - Computer arithmetic
A9.5. - Robotics

Other Research Topics and Application Domains:

B1.2.2. - Cognitive science
B2.8. - Sports, performance, motor skills
B5.1. - Factory of the future
B5.2. - Design and manufacturing
B5.6. - Robotic systems
B9.6. - Humanities
B9.9. - Ethics

1. Team, Visitors, External Collaborators

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2. Overall Objectives

2.1. 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 mechanical, physiological and cognitive capacities of humans in the form of physical constraints or objectives for the design of cobotized workstations. This design is understood in a large sense: the choice of the robot's architecture (cobot, exoskeleton, etc.), the dimensional design (human/robot workspace, trajectory calculation, etc.), the coupling mode (comanipulation, teleoperation, etc.) and control. 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 for performing a task. In 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 information available 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 the available ergonomic evaluation criteria (RULA, REBA, etc.). However, they 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 analysis may tend to see humans as a high-performance machine to be optimized. This may 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 in fact be a good long-term strategy. These questions make a direct link between motor and cognitive aspects that can be reflected in particular strategies as the fatigue or the expertise (manual and cognitive). This approach has not been widely explored in robotics to 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 human movements it induces to the robot design. Indeed, as we have been able to verify on several occasions in the context of industrial projects, between the ergonomist, expert in task analysis and psychology, and the robotician, expert in mechanics, control and computer science, there is a significant conceptual distance that makes it very difficult to analyze needs and define the specifications of the technical solution. To fill these methodological gaps, it is necessary, on the basis of case studies, to better define the notion of tasks in the context of a human/robot coupling and to establish a typology of this type of interaction by taking into account, with as much details as possible, the different physical and cognitive constraints and their potential psychological, organizational or ethical impacts.

The third challenge is related to 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 an optimal coupling from the point of view of "slow" phenomena such as fatigue. The major challenge is therefore to move from reactive to predictive control laws, 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 in terms of the physical realities they can account for and quite simple from a computational point of view.

3. Research Program

3.1. Analysis and modelling of human behavior

3.1.1. Scientific Context

The purpose of this axis is to provide metrics to assess human behavior. We place ourselves here from the point of view of the human being and more precisely of the industrial operator. 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 focus our proposals on assessing:

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

In the industrial context, the fields that best answer these questions are work ergonomics and cognitive sciences. Scientists typically work on 4 axes: physiological/biomechanical, cognitive, psychological and sociological. More specifically, we focus on biomechanical, cognitive and psychological aspects, as described by the ANACT [12], [15]. The aim here is to translate these factors into metrics, optimality criteria or constraints in order to implement them in our methodologies for analysis, design and control of the collaborative robot.

To understand our desired contributions in robotics, we must review the current state of ergonomic workstation evaluation, particularly at the biomechanical level. The ergonomist evaluates the gesture through the observation of workstations and, generally, through questionnaires. This requires long periods of field observation, followed by analyses based on ergonomic grids (e.g. RULA [30], REBA [21], LUBA [26], OWAS [25], ROSA [46],...). Until then, the use of more complex measurement systems was reserved for laboratories, particularly biomechanical laboratories. The appearance 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, postures and more generally of human movement. Thanks to these sensors, which are more or less intrusive, it is now possible to permanently install observation systems on production lines. This completely changes paradigms and opens the door to longitudinal observations. It should be noted that this is comparable to the evolution of maintenance, which becomes predictive.

On the strength of this new paradigm, *ergonomic robotics* has recently taken an interest in this type of evaluation to adapt the robot's movements in order to reduce ergonomic risk scores. This approach complements the more traditional approaches that only consider the performance of the action produced by the human in interaction with the robot. However, we must go further. Indeed, the ergonomic criteria are based on the principle that the comfort positions are distant from the human articular stops. In addition, the notation must be compatible with an observation of the human being through the eye of the ergonomist. In practice, evaluations are inaccurate and subjective [50]. Moreover, they are made for quasi-static human positions without taking into account the evolution of the person's physical, physiological and psychological state. The repetition of gestures, the solicitation of muscles and joints is one of the questions that must complete these analyses. One of the methods used by ergonomists to limit biomechanical exposures is to increase variations in motor stress by rotating tasks [47]. However, this type of extrinsic method is not always possible in the industrial context [28].

One of Auctus' objectives is to show how, through a cobot, the operator's environment can be varied to encourage more appropriate motor strategies. To do so, we must focus on a field of biomechanics that studies the intrinsic variability of the motor system allowed by the joint redundancy of the human body. This motor variability refers to the natural alternation of postures, movements and muscle activity observed in the individual to respond to a requested task [47]. This natural variation leads to differences between the motor coordinates used by individuals, which evokes the notion of motor strategy [22].

As shown by the cognitive dimension of ergonomics (see above), we believe that some of these motor strategies are a physically quantifiable reflection of the operator's cognitive state. For example, fatigue [43] and its anticipation or the manual expertise (dexterous and cognitive) of the operator which allows him to anticipate his movements over long periods of time in order to preserve his body, his performance and his pain.

3.1.2. Methodology

How can we observe, understand and quantify these human motor strategies to better design and control the behavior of the cobotic assistant? When we study the systems of equations considered (kinematic, static, dynamic, musculoskeletal), several problems appear and explain our methodological choices:

- the large dimensions of the problems to be considered, due to joint, muscle and placement redundancy,
- the variabilities of the parameters, for example: physiological (consider not an operator, but a set of operators), geometric (consider a set of possible placements of the operator) and static (consider a set of forces that the operator must produce);
- the uncertainties of measurement, model approximation.

The idea is to start from a description of redundant workspaces (geometric, static, dynamic...). To do this, we use set theory approaches, based on interval analysis [48], [36], which allow us to respond to the uncertainties and variability issues previously mentioned. In addition, one of the advantages of these techniques is that they allow the results to be certified, which is essential to address safety issues. Some members of the team has already achieved success in mechanical design for performance certification and robot design [32]. The adaptation of these approaches allows us to obtain a mapping of ergonomic and efficient movements in which we can project the operators' motor strategies and thus define a metric quantifying the sensorimotor commands chosen with regard to the cognitive criteria studied.

It is therefore necessary to:

- propose new indices linking different types of performance (ergonomic biomechanical robotics, but also influence of fatigue, stress, level of expertise on the evolution of performance);
- divide the gesture into homogeneous phases: this process is complex and depends on the type of index used and the techniques used. We are exploring several ways: inverse optimal control, learning methods, or the use of techniques from signal processing.
- develop interval extensions of the identified indices. These indices are not necessarily the result of a direct model, and algorithms need to be developed or adapted (calculation of manipulability, UCM, etc.).

- Aggregate proposals into a dedicated interval analysis library (use of and contribution to the existing ALIAS-Inria and the open source IBEX library).

The originality and contribution of the methodology is to allow an analysis taking into account in the same model the measurement uncertainties (important for on-site use of analytical equipment), the variability of tasks and trajectories, and the physiological characteristics of the operators.

Other avenues of research are being explored, particularly around the inverse optimal control [37] which allows us to project human movement on the basis of performance indices and thus to offer a possible interpretation in the analysis of behaviors.

We also use automatic classification techniques: 1) to propose cognitive models that will be learned experimentally 2) for segmentation or motion recognition, for example by testing Reservoir Computing [23] approaches.

3.2. Operator / robot coupling

3.2.1. Scientific Context

Thanks to the progress made in recent years in the field of p-HRI (Physical Human-Robot Interaction), robotic systems are beginning to operate in the same workspace as humans, which is profoundly changing industrial issues and allowing a wide variety of human-robot coupling solutions to be considered to perform the same task [14]. Different types of interactions exist. They can be classified in different ways: according to the degree of autonomy of the robot and its proximity to the user [20] with particularities for "wearable" robots" [18], [17], or for collaborative robotics [49], or according to the role of the human being [44]. From a cognitive point of view, classifications are more concerned with autonomy, the complexity of information processing and the type of communication and representation of the human being by the robot [35], [51].

We proposed a classification of cobotic systems according to the configuration of the schema of interactions between humans, robots and the environment [33], [41].

The parameters of the coupling being numerous and complex, the determination of the most appropriate type of coupling for a type of problem is an open problem [38], [34], [29]. The traditional approach consists in trying to identify and classify the various possible options and to select the one that seems most relevant with regard to the feasibility, efficiency, budget envelope and acceptability of the operator. One of the main objectives of our research project is to define a typology of cobots or cobotic systems in order to specify the methodology for developing the best solution: what are the criteria for defining the best robotic architecture, what type of coupling, what autonomy of the robot, what role for the operator, what risks for the human, what overall performance? These are the key issues that need to be addressed. To meet this methodological need, we propose an approach guided by experience on use cases obtained thanks to our industrial partners.

3.2.2. Methodology

Task analysis and human behavior modelling, discussed in the previous sections, should help to characterize the different types of coupling and interaction modalities, their advantages and disadvantages, in order to assist in the decision-making process. One of the ideas we would like to develop is to try to break down the task into a sequence of elementary gestures corresponding to simple motor actions performed in a clearly identified context and to evaluate for each of them the degree of feasibility in automatic mode or in robot assistance mode. The assessment must take into account a large number of parameters that relate to physical interactions, human-robot communication, reliability and human factors, including acceptability and impact on the valuation or devaluation of the operator's work. Concerning the evaluation of human factors, we have already begun to work on the subject within the more general framework of human systems interactions by operating Bayesian networks, drawing inspiration from the work of [16], [42].

The adoption of assessment criteria for a single domain (e. g. robotics or ergonomics) cannot guarantee that the performance of this coupling will be maximized. From design to evaluation, cross-effects must be constantly considered:

- impact of the cobot design on the user's performance: intuitiveness, adaptation to intra- and inter-individual variations, affordance, stress factors (noise, vibrations,...), fatigue factors (control laws, necessary attention,...) and motivation factors (effectiveness, efficiency, aesthetics,...);
- impact of user performance on cobot exploitation: risks of human error (attention error, perseveration, circumvention of procedures, syndrome outside the loop) [16].

In addition to purely physical assistance, some cobotic systems are designed to assist the operator in his decision-making. The issues of trust, acceptance, sharing of representations and co-construction of a shared awareness of the situation are then to be addressed [45].

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 provide them. Choosing a collaborative robot architecture is a difficult problem [27]. It is all the more when the questions are approached from both a cognitive ergonomics and robotics perspective. There are indeed major methodological and conceptual differences in these areas. It is therefore necessary to bridge these representational gaps and to propose an 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 first of all the development of a structured experimental approach aimed at characterizing the task to be carried out through a "system" analysis but also at capturing the physical markers of its realization: movements and efforts required, ergonomic stress. This characterization must be done through the prism of the systematic study of the exchange of information (and their nature) by humans in their performance of 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).

It can be summarized for the moment as:

- identify difficult jobs on industrial sites. This is done through visits and exchanges with our partners (manager, production manager, ergonomist...);
- select some of them, then observe the human in its ecological environment. Our tools allow us to produce a motion analysis, currently based on ergonomic criteria. In parallel we carry out a physical evaluation of the task in terms of expected performance and an evaluation of the operator by means of questionnaires.
- Synthesize these first results to deduce the robotic architectures to be initiated, the key points of human-robot interaction to be developed, the difficulties in terms of human factors to be taken into account.

In addition, the different human and task analyses take advantage of the different expertise available within the team. We would like to gradually introduce the evaluation criteria presented above. However, the team has already worked on the current dominant approach: the use of a virtual human to design the cobotic cell through virtual tools. However, the very large dimensions of the problems treated (modelling of the body's ddl and the constraints applied to it) make it difficult to carry out a certified analysis. We then choose to go through the calculation of the body's workspace, representing its different performances, which is not yet done in this field. The idea here is to apply set theory approaches, using interval analysis and already discussed in section

3.1.2. The goal is then to extend to intervals the constraints played in virtual reality during the simulation. This would allow the operator to check his trajectories and scenarios not only for a single case study but also for sets of cases. For example, it can be verified that, regardless of the bounded sets of simulated operator physiologies, the physical constraints of a simulated trajectory are not violated. Thus, the assisted design tools certify cases of use as a whole. Moreover, the intersection between the human and robot workspaces provides the necessary constraints to certify the feasibility of a task. This allows us to better design a cobotic system to integrate physical constraints. In the same way, we will look for ways in which human cognitive markers can be included in this approach.

Thus, we summarize here the contributions of the other research axes, from the analysis of human behavior in its environment for an identified task, to the choice of a mechanical architecture, via an evaluation of torque and interactions. All the previous analyses provide design constraints. This methodological approach is perfectly integrated into an Appropriate Design approach used for the dimensional design of robots, again based on interval analysis. Indeed, to the desired performance of the human-robot couple in relation to a task, it is sufficient to add the constraints limiting the difficulty of the operator's gesture as described above. The challenges are then 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.

3.3.2. Control design

The control of collaborative robots in an industrial context gives rise to two main issues. The first is related to the macroscopic adaptation of the robot's behavior according to the phases of the production process. The second 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 dynamic 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 [20], [31], [24], 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 appropriation 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 [39], [40]. It must exist at several levels: the level of the mission and its macroscopic description (the plan) and the level of the task being executed.

For the first level, the task plan to be performed for a given industrial operation can be represented by a finite state machine. In order not to increase the human's cognitive load by explicitly asking him to manage transitions for the robot, a high-level controller can ensure these transitions from one task (and the associated assistance mode) to another based on an online estimate of the current state of the human-robot pair. From the control point of view, it is then a question of using the richness of the multi-tasking control formalism under constraints in order to ensure a continuous transition from one control mode to another while guaranteeing compliance with a certain number of control constraints resulting from ergonomic specifications. Indeed, the reactive nature of the mission assigned to this type of robot implies the need to check at all times that the constraints intrinsic to any robot are respected: stops, control saturations, non-interpenetration of the bodies as well as those resulting from a complete ergonomic analysis. This analysis can be formally synthesized by an interval analysis approach. The guarantee of formal compliance with all these constraints at all times is strictly necessary. Indeed, if a certain number of guarantees can be provided a priori via interval analysis, compliance with the constraints resulting from it as well as with the intrinsic constraints cannot be ensured a priori. In fact, these constraints are potentially dependent on the state of the robot and its movement is subject to that of the human operator, which, by nature, is difficult to predict accurately. The control architecture to be developed must therefore allow both to specify potentially multi-tasking control problems under stress while integrating new constraints of an ergonomic nature, such as those resulting from interval analysis.

A fundamental work must also be carried out to show how the approaches generally envisaged for the control of robots interacting with humans (impedance control, active compliance, passivity, force amplification, gravity compensation, etc.) can be formulated in a generic way on the basis of an appropriate definition of tasks and safety constraints in the sense of multi-task control formalisms under constraints.

For the second level, the adaptation in question amounts to modulating the robot's involvement in the joint task according to the value of the robotic and ergonomic performance indicators determined to be relevant at the given time. The associated scientific challenge is complex because this adaptation requires establishing a link between the robot's level of involvement and a situation. If the nature of the link between the level of involvement and the control parameter for a robot acting as an effort amplifier seems quite simple, this is far from being the case for all possible forms of collaboration: mutual exclusion, coexistence, subordination, assistance, cooperation,... An approach that seeks to establish an analytical model between ergonomic situation and control law parameters is doomed to failure. Instead, we propose an incremental approach to learning this complex relationship and evolving it over time. This requires first identifying the general and relevant variables of the command law to conduct this learning in an efficient and reusable way, regardless of the particular method of calculating the order.

Moreover, a purely reactive adaptation of the control law would make no sense given the slow dynamics of certain physiological phenomena such as fatigue. The project therefore aims to formulate the order problem as a predictive problem where the impact of the order 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, this prediction requires the use of a virtual human model and possibly a dynamic simulation to quantify the impact of these potential movements in terms of performance, including ergonomics. It is unthinkable to use a predictive command with simulation in the loop with an advanced virtual manikin model. The central idea is then to adapt the prediction horizon and the complexity of the corresponding model in order to guarantee a reasonable computational complexity.

More generally, the current challenges of predictive control in robotics are related to the high non-linearity of the models as well as their dimensionality. While the use of very simplified models can be justified at the trajectory generation scale, it is not really feasible from the point of view of real-time control. Indeed, it is necessary to guarantee the existence of a solution to the control problem at each moment of the considered horizon by ensuring that the state of the system is maintained in a viable zone of the state (which can lead to very conservative control decisions) while guaranteeing a form of optimality on the horizon of control decisions. This is a major challenge and the work on this theme will again consist in developing a method for automatically simplifying the robot model that takes into account a maximum level of complexity and dimensionality. This will ensure that order decisions are fine-tuned in the very short term and that the same decisions are optimized overall in the longer term. This part of the project is ambitious but the associated research perspectives are rich and with a high potential scientific impact. Alternatively and in the shorter term, a method that does not reduce the dimensionality of the model (and thus make it possible to account for stresses at an articular level) can be explored. It would consist in using locally linear models of the robot and discrete transitions from one model to another. This would allow the formulation of a linear predictive control problem that could be solved online.

The planned developments require both an approach to modeling human sensory-motor behavior, particularly in terms of accommodating fatigue via motor variability and validating related models in an experimental framework based on observation of movement and quantification of ergonomic performance. Experimental developments must also focus on the validation of proposed control approaches in concrete contexts. To begin with, the Woobot project related to gesture assistance for carpenters (Nassim Benhahib's thesis) and a collaboration currently being set up with SAFRAN on assistance to operators in shrink-wrapping tasks (manual knotting) in aeronautics are rich enough background elements to support the research conducted.

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 capacity for adaptation is the 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 their health and well-being. How then 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 central solutions to meet this societal challenge. By assisting humans in their most dangerous and painful tasks, it complements or replaces them in their phases of physical and cognitive fragility.

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

5. Highlights of the Year

5.1. Highlights of the Year

- David Daney and Cyril Dané (AIO) were invited to the Élysée Palace to present the Numii system,
- Anna Pugach and David Daney have filed a patent entitled "Intelligent Textile Adapted for Motion and/or Deformation Detection"

6. New Software and Platforms

6.1. HuMoSoft

Human Motion Analysis Software
KEYWORDS: Movement analysis - 3D movement
FUNCTIONAL DESCRIPTION: HuMoSoft is based on the ROS platform. The acquisition data can come from different depth sensors, for example Kinect, via the Nuitrack JDK. An extended Kalman filter has been implemented, and motion analysis uses the RULA method.

- Authors: Jessica Colombel and David Daney
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- URL: https://gitlab.inria.fr/auctus/kombos-server

7. New Results

7.1. Posture and motion capture by smart textile

The objective of the work is to design a jacket made of smart textile, without the use of built-in sensors, to determine the posture of the operator.

We propose an innovative solution based on the electrical properties of a stretchable conductive tissue which is used in the manufacture of a smart garment. We use the Electrical Impedance Tomography (EIT) to reconstruct the resistance change of the conductive tissue during tissue extension/deformation caused by human movement. The conductive tissue is placed at strategic points of the jacket (e.g., elbow, shoulder). The model that describes the correlation between the operator's posture/motion and tissue deformation is difficult to obtain analytically. Neural networks are being used to associate the different postures and movements measured by the reference device with the electric field measured in the smart textile. After the learning phase, the neural network is able to predict articular angle with an accuracy of + -5 degrees from tissue extension/deformation only.

Following the successful validation on the first prototype, a request of the patent was drafted and submitted on November 6, 2018 under the number FR1860192 (Smart textile adapted for motion and/ or deformation detection). At the same time, we submitted an experiment project to COERLE. The experiments are planned for next year. This study will allow us to acquire a big database for the learning of artificial neural networks in order to try to propose a unique and stable solution of human posture capture by the smart textile, whatever the anthropometric parameters.

7.2. Appropriate design of kinematic chains

The goal of this research is to develop efficient and reliable tools based on the appropriate design framework using interval analysis that are capable of handling variations and uncertainties for the analysis and synthesis of serial kinematics chains. A primary application for this tool is to accurately model the true workspaces of the redundant human arm by imposing realistic joint constraints that may be obtained experimentally. The appropriate design framework makes it possible to model variations and uncertainties in the kinematics chains to describe families of mechanisms (e.g., sets of arms) and to understand the performance of the family. Through studying a person's usage of their available workspace on a given task, it is theorized that a task expert will make greater use of their available workspace to minimize the risk of fatigue, while a task amateur will confine themselves to a smaller region of their available workspace which will result in expedited fatigue. By understanding the range of motions of a family of task experts, collaborative robotics can be effectively incorporated to assist with the task. A C++ software library, titled the Kinematic Chain Appropriate Design Library, is being developed to efficiently model serial kinematics chains, where the main difficulty is to properly formulate the kinematic equations and incorporate additional constraints so that the problem can be quickly solved using interval analysis methods. The library will be capable of completely solving the forward and inverse kinematics problems, generating certified descriptions of various workspaces, and synthesizing appropriate design solutions.

7.3. Filtering method for human motion analysis

We have developed a series of filters to estimate the states of a dynamic system from a series of incomplete or noisy measurements for the analysis of human motion. They are also used for data fusion or for filtering noisy data from a model, especially for a Kinect and Orbbec sensor. In our case, we first developed an extended Kalman filter [13] that we improved to take into account the singularities of representations of the human kinematic module, the estimation of users' physiological parameters as well as the calibration of measurement systems. In addition, different strategies have been implemented to ensure the real-time operation of the filter, and the addition of joint constraints to improve the accuracy of the results.

In a second step, we implemented an interesting alternative technique for filtering time series. It consists of performing singular spectrum analysis. Due to the multidimensional nature of the type of data we use a specific version of this technique called Multivariate or Multidimensional Singular Spectrum Analysis (MSSA) [19].

This technique is based on a method called *decomposition into main components* which aims to compress the data both on their temporal and physical dimensions. Excellent results have been obtained.

7.4. A software architecture for the analysis of human movement and the prevention of musculoskeletal risk

Robot Operating System (ROS) is used to build the architecture of an in situ system for analyzing the movement of industrial operators. The system, presented in [5], allows us to manage data processing and modules for evaluating and recognizing a human's actions.

The ROS architecture has been chosen to guarantee a certain modularity in our system. More specifically, our objectives are to receive and merge any type of data. We want to set up an agile system that can be used in real time or in remote calculation. We also plan to use our architecture for human-robot interaction

7.5. Hamiltonian Monte Carlo with boundary reflections, and application to polytope volume calculations

In this work [7], we studied HMC with reflections on the boundary of a domain, providing an enhanced alternative to Hit-and-run (HAR) to sample a target distribution in a bounded domain. We make three contributions. First, we provide a convergence bound, paving the way to more precise mixing time analysis. Second, we present a robust implementation based on multi-precision arithmetic – a mandatory ingredient to guarantee exact predicates and robust constructions. Third, we use our HMC random walk to perform polytope volume calculations, using it as an alternative to HAR within the volume algorithm by Cousins and Vempala. The tests, conducted up to dimension 50, show that the HMC RW outperforms HAR.

This work is a collaboration with Frédéric Cazals and Augustin Chevallier from the ABS team at Inria Sophia-Antipolis. Augustin Chevallier visited our team on May 17-18, 2018. Volume calculation is a topic of interest for AUCTUS in light of the volume of configuration spaces.

7.6. Classification of cobotic systems

A new classification of cobotic systems has been proposed [1]. As there are many different ways to classify robots (robotic architecture, size, autonomy, moving ability, adaptability, etc.) and to classify human work or human roles, classifying cobotic systems (the teams formed by a robot and a human operator) is a complex problem. We proposed to focus on information exchanges and interactions among the robot, the human operator and objects of the environment. The graph describing these interactions provides interesting clues to classify cobotic systems. For example, in the surgical robotics and drone domains, the human operator is typically teleoperating (no direct contact with the environment) with constant information exchanges between him and the robot. For that reason, the graph describing these interactions called "scheme of interactions" is very specific. Further on, the description with a scheme of interactions seems particularly appropriate for cobotic systems classification. Several schemes present discriminant features that allow the qualification and naming of the cobotic systems. It is thus possible to identify the symbiotic system, with a constant information exchange and an efficient work sharing (drone), the augmented human case (work with exoskeleton), the subcontracting case, the assistance to effort case and the intelligent assistance case.

7.7. Use of Bayesian networks for situation awareness risks prediction

In all domains involving complex human systems interactions, such as the robotic domain, human errors may have dramatic impacts. These errors are often linked to situation awareness issues. We recently proposed a new method to predict situation awareness errors in training simulations [2]. It is based on Endsley's model and the 8 "situation awareness demons" that she described. The predictions are determined thanks to a Bayesian network and Noisy-Or nodes. A maturity model is introduced to come up with the initialization problem. The NASA behavioral competency model is also used to take individual differences into account.

7.8. Classification of human actions

It is important for the decomposition of human industrial activities to recognize and classify elementary gestures (a possible decomposition for measuring difficulty is described in section 8.3 or classical methods in industry such as MTM Methods Time Measurement). Due to the temporal nature of the signals, it is necessary to use a type of deep networks that manage this type of data. Recursive networks are therefore used where past observations influence the current prediction. Among recent deep network research, the so-called *long-short term memory* (LSTM) cells, represented here, seem well adapted. Unlike a simple recursive network where only data from the previous time is used for a new prediction, an LSTM cell can store data over a much longer period of time. With each prediction, the *forget gate* can decide to authorize the use or forget a previously observed data. We tested our algorithms on a classic benchmark (NTU RGB+D). In order to obtain interesting recognition rates, we showed that it was necessary to use the filters explained in section 7.3 to determinate the number of learning movements. Other less data-intensive methods are to be tested.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral contract with AIO, motion analysis issues

In partnership with the SME AIO, we are co-developing a Numii product (presented at CES 2018, 2019) capable of associating a score based on ergonomic indices with a gesture. The work focused on the software architecture, different given fusion filter, task classification, and on the gesture evaluation indices. Models and algorithms are generic for different types of sensors.

8.2. Bilateral contract with VINCI Energies

A contract has been signed with VINCI Energies for a study entitled: "Pré-étude pour la conception d'un système d'assistance aux opérateurs du bâtiment". The objective was to carry out an ergonomic analysis of the work station for operators working in the building construction domain. Operators such as electricians or plumbers were typically concerned. They indeed have to work regularly on an elevated deck with arms above shoulders, which is a well-known cause of musculoskeletal disorders. Different solutions have been proposed and investigated. A specific exoskeleton was finally chosen and its performance and acceptability are currently evaluated by VINCI Energies. This study has been performed with the help of a student named Virginie Roupenel through an internship that was funded by CEGELEC, a partner from VINCI Energies. Remarkably, the student used the system that we developed for real time analysis of operator moves.

8.3. Bilateral contract with AIO, ergonomic issues

AIO was working on a project called Kombos (now called NUMII). The objective of the project is to design an automatic system that analyses operator moves in real time and determines ergonomic scores, which are then sent to a server and stored in a database. One of the main problems was to find a strategy to decompose a sequence of moves in elementary moves that could be automatically assessed according to standard ergonomic scores. After discussion, AIO decided to contract with us (under the direction of Jean-Marc Salotti) a study on ergonomic issues. They provided a short video of an operator manipulating tubes and they requested an ergonomic analysis in order to determine the best decomposition of the operator's activity into elementary movements. We subcontracted ergonomic studies to ERSYA, a company that is specialized in that domain and added our expertise on human system interactions to provide technical complements.

8.4. Bilateral contract with Orange

The Orange company is lacking feedback for the customers interacting with the website and the chat bot dedicated to customer assistance. In order to better understand the sentiment, feelings and satisfaction of the customer, Orange and us agreed on a research work carried out by a PhD student under the direction of Jean-Marc Salotti. Nicolas Simonazzi has been recruited and he started his PhD work in May 2018. He already performed a state of the art on chat bots, sentiment analysis and online assistance tools. He is currently designing an experiment with a simplified chat bot with the objective of testing emotional changes and observing changing behaviors.

8.5. Bilateral contract with CATIE

A bilateral contract has been signed with CATIE (Centre Aquitain des Technologies de l'Information et de l'Electronique) for the study of the links between electric consumption and human systems interactions in buildings of the tertiary sector. The study started in September 2017 and is carried out under the supervision of Jean-Marc Salotti. A large amount of data has been collected (electric consumption, temperature, human presence, etc.) and is currently analyzed. The objective is to help predicting energy consumption in the following days for different parts of the buildings.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Woobot

The main objective of Woobot is to propose a methodology for designing and controlling a collaborative robotic system to assist and secure an operator's actions. The system must preserve the health and sensory expertise of the operator while guaranteeing his or her mobility. Motivated by a pilot case from carpentry, the determination of the behavior of the collaborative robot will be based on a human-centered approach and based on a precise ergonomic analysis of the task and the biomechanical performances and needs of the operator. Two scientific issues are important: the choice of the system architecture (type of collaborative robot, number of degrees of freedom, level of redundancy with respect to the task, type of interaction of the collaborative robot with the task and/or the human...), and the behavior of the collaborative robot that must be implemented in the control. To answer these questions, it is then necessary to consider in the same formalism the human and task constraints from the point of view of:

- of the performance necessary for the task (cutting forces, trajectories);
- of the operator's biomechanical performance (kinematics -i.e. dexterity; static -i.e. manipulability and human dynamics).
- ergonomic (task, work environment, human posture).

9.2. International Research Visitors

9.2.1. Visits of International Scientists

- Gionata Salvietti, Affiliated Researcher at IIT Central Research Lab Genova, Italy, visited the team on February 7-8, 2018 and gave a talk.
- Milan Hladík, Associate Professor at Charles University in Prague, Czech Republic, visited the team on August 21-24, 2018.
- Chee Yap, Professor at the Courant Institute of Mathematical Sciences at New York University, visited the team on December 6-7, 2018. He gave a talk entitled "New Approach to FIND-PATH: a Paradigmic Problem in Robotics, AI and SC".

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

Within the Human Systems Integration DAS of the AESE Pole (see expertise section), a daily workshop has been organized the 9/11/2018 at Agen Agropole. The title of the workshop was: "Comment l'IA peut-elle améliorer l'interaction homme-machine?". Jean-Marc Salotti and David Daney participated to the organization of the workshop. Jean-Marc Salotti presented a talk entitled: "Introduction aux concepts de l'intelligence artificielle".

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- David Daney co-organized the international workshop *"Assistance and Service Robotics in a Human Environment: From Personal Mobility Aids to Rehabilitation-Oriented Robotics* at IROS 2018, Madrid.

10.1.2.2. Member of the Conference Program Committees

- IROS 2018 (IEEE/RSJ International Conference on Intelligent Robots and Systems) [Vincent Padois, associate editor]
- ICRA 2019 (IEEE/RAS International Conference on Robotics and Automation) [Vincent Padois, associate editor]

10.1.2.3. Reviewer

- ICRA 2019 (2019 IEEE International Conference on Robotics and Automation) [Vincent Padois, David Daney]
- IROS 2018 (IEEE/RSJ International Conference on Intelligent Robots and Systems) [David Daney, Vincent Padois]
- Humanoids 2018 (IEEE-RAS International Conference on Humanoid Robots) [Ganna Pugach]
- International Symposium on Experimental Robotics 2018 [Vincent Padois]

10.1.3. Journal

10.1.3.1. Reviewer - Reviewing Activities

- Mechanism and Machine Theory [David Daney]
- Acta Astronautica [Jean-Marc Salotti]
- International Journal of Human Factors Modelling and Simulation [Jean-Marc Salotti]
- behavioral Brain Research [Jean-Marc Salotti]
- Frontiers in Robotics and Artificial Intelligence [Vincent Padois]
- International Journal of Humanoid Robotics [Vincent Padois]
- Robotics and Automation Letters [Vincent Padois]

10.1.4. Invited Talks

- Sylvain Pion gave a talk entitled "The Arithmetic Toolbox in CGAL" at the iRRAM-MPFR-MPC Developers Meeting, in Dagstuhl, Germany on April 18-20, 2018, organized by Paul Zimmermann.
- Jean-Marc Salotti gave a talk at the 18th European Mars Conference that took place in La-Chaux-de-Fonds, Suisse, August 26th to 28th 2018. The title of his conference was "European Mars mission architecture using an enhanced Ariane launcher".
- Vincent Padois gave a talk entitled "Human-Robot Physical Interaction – Various considerations on collaborative robotics with control in mind" at the 2nd School on Robotics and Social Interactions, in Moliets-et-Maâ, France on October, the 3rd 2018, organized by Ghiles Mostafaoui.
- Vincent Padois gave a talk entitled "GT7 on Humanoid Robotics - An overview of activities in 2017-2018 and some perspectives" at the national biennial meeting of the "Groupement de recherche en Robotique", in Paris, France on November, the 22nd 2018.

10.1.5. Leadership within the Scientific Community

Vincent Padois is, together with Olivier Stasse from LAAS, the co-animator of GT7 "Humanoid Robotics" of the CNRS "Groupement de Recherche en Robotique" (GDR). The role of animator consists in organizing regular workshops in humanoid robotics with the members of the French research community in this domain. It also consists in reporting strategic elements to the GDR in order to better organize the structure of research in Robotics in France.

10.1.6. Scientific Expertise

Jean-Marc Salotti and David Daney are official animators of the Humans Systems Interactions AESE DAS (Strategic Activities Domain of the Aerospace Valley Pole), which gathers all regional actors concerned with human factors, human systems interactions, and collaborative robotics mainly in the aerospace sector, but not limited to that domain. At least 2 daily workshops are organized each year for the members of the group in order to focus on a specific issue. Jean-Marc Salotti and David Daney are also solicited to examine regional projects linked to the DAS in order to provide advice and eventually to participate to the labelling process of the pole.

10.1.7. Research Administration

Sylvain Pion represents the Auctus team in the CUMI-R (Comité des Utilisateurs des Moyens Informatiques) committee of Inria Bordeaux.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: Jean-Marc Salotti, Intelligence Artificielle, 103,5h éqTD, M1, Ecole Nationale Supérieure de Cognitique / Bordeaux INP, France

Master: Jean-Marc Salotti, Facteurs Humains et Ingénierie Cognitique, 15h éqTD, M1, Ecole Nationale Supérieure de Cognitique / Bordeaux INP, France

Master: Jean-Marc Salotti, Interactions Hommes Robots, 15h éqTD, M2, Ecole Nationale Supérieure de Cognitique / Bordeaux INP, France. In this course, all students have practical works involving cobotic systems: programming NAOs and UR3 (Universal Robots) and testing an exoskeleton.

Master: David Daney, Interactions Hommes Robots, 3h éqTD, M2, Ecole Nationale Supérieure de Cognitique / Bordeaux INP, France.

Master: David Daney, Mathématiques pour la robotique, 24h éqTD, M2, Enseirb/Ensc, Bordeaux INP, France.

Master: Vincent Padois, Literature review - What, Why and How?, 20h éqTD, M2, Enseirb/Ensc, Bordeaux INP, France.

10.2.2. Supervision

Defended PhD

- Aurélien Massein, “Conception d’environnement instrumenté pour la veille à la personne”, Université Côte d’Azur, 2018/11/22

PhD in progress:

- Nassim Benhabib (Inria / Région NA – Woobot project), “Méthodologie de conception et de commande d’un système robotique collaboratif pour assister et sécuriser les gestes d’un opérateur”, November 2018 – , David Daney and Vincent Padois
- Nicolas Simonazzi (CIFRE Orange), “Analyse comportementale et détection des émotions dans le cadre de l’utilisation de chat-bots en ligne”, May 2018 –, Jean-Marc Salotti
- Olfa Jema (Cotutelle Université de Sousse, Tunisie), “Analyse du mouvement humain”, December 2017 –, Lotfi Romdhane, Sami Bennour, David Daney
- Pierre Laguillaumie (Thèse laboratoire PPRIME), “Méthodologie pour la mise en œuvre d’un robot collaboratif de nouvelle génération prenant en compte la sécurité et le confort biomécanique de l’opérateur en situation de travail”, March 2018 – , Jean-Pierre Gazeau and Vincent Padois

10.2.3. Juries

Vincent Padois:

- PhD jury of Thomas Flayols, Examinator, “Exploitation du Retour en Force Pour l’Estimation et le Contrôle des Robots Marcheurs”, Université Fédérale de Toulouse Midi-Pyrénées, 2018/10/12
- PhD jury of David Busson, Reviewer, “Gestion de manipulateurs mobiles et redondants en environnement contraint et dynamique”, École Nationale Supérieure d’Arts et Métiers, 2018/11/26
- PhD jury of Lucas Joseph, Thesis advisor, “An energetic approach to safety in robotic manipulation”, Sorbonne Université, 2018/12/07
- PhD jury of Philipp Schlehuber-Caissier, Thesis advisor, “Contributions to robotic control design with formal stability and safety guarantees”, Sorbonne Université, 2018/12/14
- PhD jury of Florian Golemo, Examinor, “How to Train Your Robot – New Environments for Robotic Training and New Methods for Transferring Policies from the Simulator to the Real Robot”, Université de Bordeaux, 2018/12/19

David Daney:

- PhD jury of Baptiste Bush, Examinator, “Optimization techniques for an ergonomic human-robot interaction”, Université de Bordeaux, 2018/02/27
- PhD jury of Joshua Kevin Pickard, Reviewer, “Analysis and Synthesis Methods for the Appropriate Design of Parallel Mechanisms”, University of New Brunswick, Canada, 2018/03/29
- PhD jury of Aurelien Massein, Thesis advisor, “Conception d’environnement instrumenté pour la veille à la personne”, Université Côte d’Azur, 2018/11/22
- PhD jury of Oriane Dermy, Reviewer, “Prédiction du mouvement humain pour la robotique collaborative: du geste accompagné au mouvement corps entier”, Université de Lorraine, 2018/12/17
- PhD jury of Adrien Koessler, Invited, “Contribution à l’agrandissement de l’espace de travail opérationnel des robots parallèles”, Université Clermont Auvergne, 2018/12/19

10.3. Popularization

10.3.1. Articles and contents

- Jean-Marc Salotti published an article entitled “La robotique humanoïde”, published in Questions Internationales [8]. It briefly describes the main issues and trends in humanoid robotics. Questions Internationales is a journal from La Documentation Française, which is a brand of the “Direction de l’Information Légale et Administrative”, under the direction of the Central Administration of the French Prime Minister.
- David Daney was interviewed regarding the collaboration of Auctus with AIO on the Numii project [10], [11].

10.3.2. Education

- Collaboration with IUT Angoulème. A delegation of professors from IUT Angoulème, GEII Department, came to visit us on December 4, in order to benefit from our expertise on the use of UR3 (Universal Robots) for teaching activities.

10.3.3. Interventions

- Unithé ou café, Inria Bordeaux, February 26: Anna Pugach gave a presentation: “Le textile intelligent”
- Journée portes ouvertes, 10 ans Inria Bordeaux, September 27: Vincent Padois gave demonstrations on collaborative robotics with the Panda robot

- Village des Sciences, Cap Sciences, Bordeaux, October 13: Jean-Marc Salotti animated a movie/debate: “Un robot peut-il partager vos émotions?”
- Village des Sciences, Cap Sciences, Bordeaux, October 14: Vincent Padois and David Daney gave demonstrations on collaborative robotics with the Panda robot
- ENSC inauguration, November 30: Nassim Benhabib gave demonstrations on collaborative robotics with the Panda robot

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