IN PARTNERSHIP WITH:
CNRS

Ecole Centrale de Lille

Université de Lille

Activity Report 2019

Project-Team DEFROST

DEFormable RObotics SofTware

IN COLLABORATION WITH: Centre de Recherche en Informatique, Signal et Automatique de Lille

RESEARCH CENTER
Lille - Nord Europe

THEME
Robotics and Smart environments

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Project-Team DEFROST

Creation of the Team: 2015 January 01, updated into Project-Team: 2017 November 01

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1. Team, Visitors, External Collaborators

Research Scientists

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Olivier Goury [Inria, Researcher]
Gang Zheng [Inria, Researcher, HDR]

Faculty Members

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Alexandre Kruszewski [Ecole centrale de Lille, Associate Professor]

Post-Doctoral Fellow

Stefan Escaida Navarro [Inria, Post-Doctoral Fellow, until Nov 2019]

PhD Students

Walid Amehri [Inria, PhD Student]
Pierre Schegg [Robocath, PhD Student, granted by CIFRE]
Maxime Thieffry [Université de Valenciennes et du Hainaut Cambrésis, PhD Student, until Oct 2019]
Félix Vanneste [Inria, PhD Student]
Ke Wu [Inria, PhD Student, from Oct 2019]

Technical staff

Yinoussa Adagolodjo [Inria, Engineer, from Mar 2019]
Eulalie Coevoet [Inria, Engineer, until May 2019]
Stefan Escaida Navarro [Inria, Engineer, from Dec 2019]
Meichun Lin [Université de Lille, Engineer]

Bruno Carrez [Inria, Engineer]
Damien Marchal [CNRS, Engineer]
Bruno Marques [Inria, Engineer]
Thor Morales Bieze [Inria, Engineer]
Zhongkai Zhang [Inria, Engineer, until Aug 2019]

Interns and Apprentices

Paul Chaillou [Inria, from Jun 2019 until Aug 2019]
Antoine Delvas [Inria, from Mar 2019 until Aug 2019]
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Eve Le Guillou [from Jul 2019 until Aug 2019]

Administrative Assistant

Anne Rejl [Inria]

Visiting Scientists

Margaret Koehler [Université de Lille, Jul 2019]
Van Pho Nguyen [JAIST Japan, from Apr 2019 until Sep 2019]
Federico Renda [Khalifa University, Abu Dhabi, Jun 2019]

2. Overall Objectives

2.1. Overall Objectives

The team DEFROST aims to address the open problem of control and modelling methods for deformable robots by answering the following challenges:

- Providing numerical methods and software support to reach the real-time constraint needed by robotic systems: the numerical solutions for the differential equations governing the deformation generate tens of thousands degrees of freedom, which is three orders of magnitude of what is frequently considered in classical methods of robotic modelling and control.
- Integrating deformation models in the control methods of soft robot: In soft-robotics, sensing, actuation and motion are coupled by the deformations. Deformable models must be placed at the heart of the control algorithm design.
- Investigating predictable interaction models with soft-tissues and parameter estimation by visual feedback from medical imaging: On the contrary too many cases in surgical robotics, the contact of the soft robot with the anatomy is permitted and it creates additional deformations on the robot.

3. Research Program

3.1. Introduction

Our research crosses different disciplines: numerical mechanics, control design, robotics, optimisation methods and clinical applications. Our organisation aims at facilitating the team work and cross-fertilisation of research results in the group. We have three objectives (1, 2 and 3) that correspond to the main scientific challenges. In addition, we have two transverse objectives that are also highly challenging: the development of a high performance software support for the project (objective 4) and the validation tools and protocols for the models and methods (objective 5).

3.2. Objective 1: Accurate model of soft robot deformation computed in finite time

The objective is to find concrete numerical solutions to the challenge of modelling soft robots with strong real-time constraints. To solve continuum mechanics equations, we will start our research with real-time FEM or equivalent methods that were developed for soft-tissue simulation. We will extend the functionalities to account for the needs of a soft-robotic system:

- Coupling with other physical phenomenons that govern the activity of sensors and actuators (hydraulic, pneumatic, electro-active polymers, shape-memory alloys...).
- Fulfilling the new computational time constraints (harder than surgical simulation for training) and find better tradeoff between cost and precision of numerical solvers using reduced-order modelling techniques with error control.
- Exploring interactive and semi-automatic optimisation methods for design based on obtained solution for fast computation on soft robot models.

3.3. Objective 2: Model based control of soft robot behavior

The focus of this objective is on obtaining a generic methodology for soft robot feedback control. Several steps are needed to design a model based control from FEM approach:

- The fundamental question of the kinematic link between actuators, sensors, effectors and contacts using the most reduced mathematical space must be carefully addressed. We need to find efficient algorithms for real-time projection of non-linear FEM models in order to pose the control problem using the only relevant parameters of the motion control.
- Intuitive remote control is obtained when the user directly controls the effector motion. To add this functionality, we need to obtain real-time inverse models of the soft robots by optimisation. Several criteria will be combined in this optimisation: effector motion control, structural stiffness of the robot, reduce intensity of the contact with the environment...
- Investigating closed-loop approaches using sensor feedback: as sensors cannot monitor all points of the deformable structure, the information provided will only be partial. We will need additional algorithms based on the FEM model to obtain the best possible treatment of the information. The final objective of these models and algorithms is to have robust and efficient feedback control strategies for soft robots. One of the main challenge here is to ensure / prove stability in closed-loop.

3.4. Objective 3: Modeling the interaction with a complex environment

Even if the inherent mechanical compliance of soft robots makes them safer, more robust and particularly adapted to interaction with fragile environments, the contact forces need to be controlled by:

- Setting up real-time modelling and the control methods needed to pilot the forces that the robot imposes on its environment and to control the robot deformations imposed by its environment. Note that if an operative task requires to apply forces on the surrounding structures, the robot must be anchored to other structures or structurally rigidified.
- Providing mechanics models of the environment that include the uncertainties on the geometry and on the mechanical properties, and are capable of being readjusted in real-time.
- Using the visual feedback of the robot behavior to adapt dynamically the models. The observation provided in the image coupled with an inverse accurate model of the robot could transform the soft robot into sensor: as the robot deforms with the contact of the surroundings, we could retrieve some missing parameters of the environment by a smart monitoring of the robot deformations.

3.5. Objective 4: Soft Robotics Software

Expected research results of this project are numerical methods and algorithms that require high-performance computing and suitability with robotic applications. There is no existing software support for such development. We propose to develop our own software, in a suite split into three applications:

- The first one will facilitate the design of deformable robots by an easy passage from CAD software (for the design of the robot) to the FEM based simulation.
- The second one is an anticipative clinical simulator. The aim is to co-design the robotic assistance with the physicians, thanks to a realistic simulation of the procedure or the robotic assistance. This will facilitate the work of reflection on new clinical approaches prior any manufacturing.
- The third one is the control design software. It will provide the real-time solutions for soft robot control developed in the project.

3.6. Objective 5: Validation and application demonstrations

The implementation of experimental validation is a key challenge for the project. On one side, we need to validate the model and control algorithms using concrete test case example in order to improve the modelling and to demonstrate the concrete feasibility of our methods. On the other side, concrete applications will also feed the reflexions on the objectives of the scientific program.

We will build our own experimental soft robots for the validation of objectives 2 and 3 when there is no existing "turn-key" solution. Designing and making our own soft robots, even if only for validation, will help the setting-up of adequate models.

For the validation of objective 4, we will develop "anatomical soft robot": soft robot with the shape of organs, equipped with sensors (to measure the contact forces) and actuators (to be able to stiffen the walls and recreate natural motion of soft-tissues). We will progressively increase the level of realism of this novel validation set-up to come closer to the anatomical properties.

4. Application Domains

4.1. Industry

Robotics in the manufacturing industry is already widespread and is one of the strategies put in place to maintain the level of competitiveness of companies based in France and to avoid relocation to cheap labor countries. Yet, in France, it is considered that the level of robotization is insufficient, compared to Germany for instance. One of the challenges is the high investment cost for the acquisition of robotic arms. In recent years, this challenge has led to the development of "generic" and "flexible" (but rigid) robotic solutions that can be mass produced. But their applicability to specific tasks is still challenging or too costly. With the development of 3D printing, we can imagine the development of a complete opposite strategy: a "task-specific" design of robots. Given a task that needs to be performed by a deformable robot, we could optimize its shape and its structure to create the set of desired motions. A second important aspect is the reduction of the manufacturing cost: it is often predicted that the cost of deformable robots will be low compared to classical rigid robots. The robot could be built on one piece using rapid prototyping or 3D printers and be more adapted for collaborative work with operators. In this area, using soft materials is particularly convenient as they provide a mass/carried load ratio several orders of magnitude higher than traditional robots, highly decreasing the kinetic energy thus increasing the motion speed allowed in presence of humans. Moreover, the technology allows more efficient and ergonomic wearable robotic devices, opening the option for exo-skeletons to be used by human operators inside the factories and distribution centers. This remains to be put in place, but it can open new perspectives in robotic applications. A last remarkable property of soft robots is their adaptability to fragile or tortuous environments. For some particular industry fields (chemistry, food industry...) this could also be an advantage compared to existing rigid solutions. For instance, the German company http://www.festo.com, key player in the industrial robotics field, is experimenting with deformable trunk robots that exhibit great compliance and adaptability, and we are working on their accurate control.

4.2. Personal and service robotics

The personal and service robotics are considered an important source of economic expansion in the coming years. The potential applications are numerous and in particular include the challenge of finding robotic solutions for active and healthy aging at home. We plan to develop functional orthosis for which it is better not to have a rigid exoskeleton that is particularly uncomfortable. These orthosis will be ideally personalized for each patient and built using rapid prototyping. On this topic, the place of our team will be to provide algorithms for controlling the robots. We will find some partners to build these robots that would fall in the category of "wearable robots". With this thematic we also connect with a strong pole of excellence of the region on intelligent textiles (see Up-Tex) and with the strategic plan of Inria (Improving Rehabilitation and Autonomy).

4.3. Entertainment industry and arts

Robots have a long history with entertainment and arts where animatronics have been used for decades for cinematographic shootings, theater, amusement parks (Disney's audio-animatronic) and performing arts. We believe that soft robots could be a good support for art. As an example, last year we collaborated with the artist Dewi Brunet in the creation of animated origami structures (see https://dewiorigami.com/).

Figure 1. Dewi Brunet and his "Origami 2.0" exhibit at the AMV in Trélon

4.4. Medical Applications

Soft robots have many medical applications as their natural compliance makes them safer than traditional robots when interacting with humans. Such robots can be used for minimally invasive surgery, to access and act on remote parts of the body through minimal incisions in the patient. Applications include laparascopic and

brain surgery, treatment of several cancers including prostate cancer, and cardiology, for example percutaneous coronary interventions.
As an example, we received an industry grant (CIFRE) with Robocath to work on autonomous catheter navigation. See section 8.2. Another application is cochlear implant surgery.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Fondamental results

Three PhD students have defended excellent thesis in 2019:

- **Eulalie Coevoet**: Optimization-Based Inverse Model of Soft Robots With Contact Handling
- **Zhongkai Zhang**: Vision-based Calibration, Position Control and Force Sensing for Soft Robots
- **Maxime Thieffry**: Dynamic control of soft robots

In each of these thesis we presented fundamental results on the team's roadmap. Eulalie Coevoet presented the first algorithms that allow inversing the robot model in contact situations. It can be used for planning, manipulation and locomotion. Zhongkai Zhang's results allow the use of the robot as a generalized force sensor thanks to vision. We use that for feedback control for both position and force. Maxime Thieffry developped the first method for dynamic control based on model order reduction. The method is very generic and significantly improves the precision of soft robots.

5.1.2. Awards for software development

DEFROST actively contributed to the open source community by developing plugins for the SOFA framework. The team participated in the SofaWeek2019, during which the SOFA consortium organized the "Open-Source SOFA awards". One prize was offered to the candidate who developed the best open source plugin for SOFA. Another prize was offered to the best open source plugin according to the public (conference attendants). **Both prizes were won by the DEFROST team**, for the Model Order Reduction plugin and the SofaPython3 plugin respectively: link.

5.1.3. Organization of workshops and tutorials

This year, special effort was expended on the promotion of our tools through the organization of workshops and tutorials. A full tutorial day about our tools was organized at the IEEE International Conference on Soft Robotics (RobotSoft019). We then organized the first Journée de Robotique Souple in Lille with 70 participants from 9 countries. The team also participated in the organization of the (2nd Workshop on Proximity Perception in Robotics) at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019).

5.1.4. ANR project ROBOCOP

The project ROBOCOP (ROBOtization of COchlear ImPlant) was funded by the ANR (Agence nationale de la recherche) for the development of cochlear implants for the future that are activated by electroactive polymers. The project is in collaboration with the IEMN, the LPPI, Inserm and Oticon Medical. This project will allow us to fund a PhD Student and a postdoctoral fellow for 2 years.

6. New Software and Platforms

6.1. SOFA

Simulation Open Framework Architecture

KEYWORDS: Real time - Multi-physics simulation - Medical applications

FUNCTIONAL DESCRIPTION: SOFA is an Open Source framework primarily targeted at real-time simulation, with an emphasis on medical simulation. It is mostly intended for the research community to help develop new algorithms, but can also be used as an efficient prototyping tool. Based on an advanced software architecture, it allows : the creation of complex and evolving simulations by combining new algorithms with algorithms already included in SOFA, the modification of most parameters of the simulation (deformable behavior, surface representation, solver, constraints, collision algorithm, etc.) by simply editing an XML file, the building of complex models from simpler ones using a scene-graph description, the efficient simulation of the dynamics of interacting objects using abstract equation solvers, the reuse and easy comparison of a variety of available methods.

- Participants: Christian Duriez, François Faure, Hervé Delingette and Stéphane Cotin
- Partner: IGG
- Contact: Hugo Talbot
- URL: http://www.sofa-framework.org

6.2. SoftRobots

SoftRobots plugin for Sofa

KEYWORDS: Numerical simulations - Problem inverse - Soft robotics

FUNCTIONAL DESCRIPTION: This plugin allows the modeling of deformable robots in the Sofa platform. It allows the modeling of different actuators, such as cable, pneumatic pressure, hydraulics and other simpler types of actuation. It also contains useful tools for animation design or communication with the robot. Coupled with the SoftRobots.Inverse plugin, it also allows the control of these robots. More information can be found on the dedicated website.

- Participants: Christian Duriez, Olivier Goury, Jérémie Dequidt, Damien Marchal, Eulalie Coevoet and Félix Vanneste
- Contact: Christian Duriez
- URL: https://project.inria.fr/softrobot/

6.3. Model Order Reduction Plugin for SOFA

KEYWORDS: Model Order Reduction - Sofa - Finite element modelling

SCIENTIFIC DESCRIPTION: This plugin allows speed-up of SOFA simulations by providing tools to create a reduced version of the SOFA simulation that runs at much higher rates but remains accurate. Starting with a snapshot of the object deformations on a high-dimensional Finite Element mesh, Proper Orthogonal Decomposition (POD) is used to compute a reduced basis of small dimension representing correctly all the possible deformations of the object. The original system describing the object motion is then greatly reduced. To keep numerical efficiency, a hyper-reduction method is used to speed-up the construction of the reduced system.

FUNCTIONAL DESCRIPTION: This plugin allows to dramatically reduce computational time in mechanical simulation in the SOFA framework. A reduced simulation, of much smaller dimension but still accurate is created in an automatic way by the plugin. Building the reduced model may take time, but this operation is made once only. The user can then benefit from a reduced and interactive version of his/her simulation without significant loss of accuracy.

RELEASE FUNCTIONAL DESCRIPTION: This is the first version of the plugin.

NEWS OF THE YEAR: Publication using this plugin accepted dans IEEE Transactions on Robotics

- Participants: Olivier Goury, Félix Vanneste, Christian Duriez and Eulalie Coevoet
- Contact: Olivier Goury
- Publication: Fast, generic and reliable control and simulation of soft robots using model order reduction
- URL: https://project.inria.fr/modelorderreduction/

6.4. SoftRobots.Inverse

KEYWORDS: Sofa - SoftRobots

FUNCTIONAL DESCRIPTION: This plugin builds on the plugin SoftRobots. Inside the plugin, there is some constraint components that are used to describe the robot (effectors, actuators, sensors). An optimisation algorithm is provided to find the efforts to put on actuators in order to place the robot in a the closest possible configuration than the one described by "effectors", or to a state described by "sensors". This method used to control the soft-robots in the task space is patented.

- Partners: CNRS - Université de Lille - Ecole Centrale de Lille
- Contact: Christian Duriez
- URL: https://project.inria.fr/softrobot.inverse

6.5. SofaPython3

KEYWORDS: Python - Numerical simulations - Sofa

FUNCTIONAL DESCRIPTION: This plugin allows to use Sofa as a library from any python3 program. It also allows to write new mechanical component for a Sofa simulation in python3.

- Contact: Christian Duriez
- URL: https://github.com/SofaDefrost/plugin.SofaPython3/

6.6. SofaQtQuick

runSofa2

KEYWORDS: Sofa - GUI (Graphical User Interface) - Modeling - Physical simulation

FUNCTIONAL DESCRIPTION: Smooth the user experience with Sofa By integrating authoring features into runSofa so we can design simulation in an integrated environment. We should be able to model scenes, simulate & debug them.

This tool replaces the old "runSofa" interface, today deprecated but still in use by most SOFA users.

SofaQtQuick provides a fluid and dynamic user experience for SOFA, thanks to the integration of authoring tools to design complex simulations directly in the 3D environment, rather that scripting them as it is done today.

FEATURES:

*Scene graph editing

*Interactive modeling

*Project oriented approach

*Prefab as reusable and parametric object

*2D Canvas

*Custom widgets per component

*Live coding

*Node base interface for data link debugging

*Everything with a non-linear workflow

Based on a code gift from Anatoscope, stringly inspired by Blender & Unity's workflow.

RELEASE FUNCTIONAL DESCRIPTION: 1st Beta version, unstable, but testable.

- Contact: Christian Duriez
- URL: http://github.com/SofaDefrost/SofaQtQuick

7. New Results

7.1. Soft robots locomotion and manipulation control using FEM simulation and quadratic programming

In this work, we proposed a method to control the motion of soft robots able to manipulate objects or roll from one place to another. We used the Finite Element Method (FEM) to simulate the deformations of the soft robot, its actuators, and its environment. To find the inverse model of the robot interacting with obstacles, and with constraints on its actuators, we wrote the problem as a quadratic program with complementarity constraints. The novelty of this work was that friction contacts (sticking contact only) is taken into account in the optimization process, allowing the control of these specific tasks that are locomotion and manipulation. We proposed a formulation that simplifies the optimization problem, together with a dedicated solver [22]. The algorithm had real-time performance and handles evolving environments as long as we know them. To show the effectiveness of the method, we presented several numerical examples, and a demonstration on a real robot (see Figure 2 and 3).

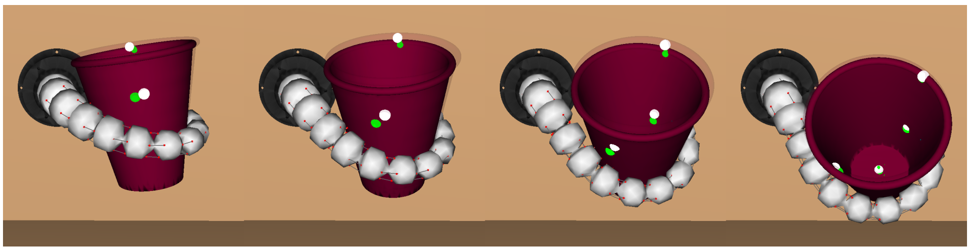

Figure 2. Simulation of a soft gripper holding a deformable cup subject to gravity. Here we optimize the cables displacements to control the position/orientation of the cup. A phantom of the cup target is shown in transparency. The cup have four controlled points represented by the green spheres. The corresponding targets are represented by the white spheres.

7.2. Toward Shape Optimization of Soft Robots

This year, we obtained new results on shape optimization for soft robotics where the shape is optimized for a given soft robot usage. To obtain a parametric optimization with a reduced number of parameters, we relied on an approach where the designer progressively refines the parameter space and the fitness function until a satisfactory design is obtained. In our approach, we automatically generate FEM simulations of the soft robot and its environment to evaluate a fitness function while checking the consistency of the solution. Finally, we have coupled our framework to an evolutionary optimization algorithm, and demonstrated its use for optimizing the design of a deformable leg of a locomotive robot. A paper presenting the approach was accepted at IEEE/International Conference On Soft-Robotics2019 [29].

Figure 3. Real soft robot actuated online using the output of the simulation. In this scenario, using our control framework, we are able to control the orientation of the real plastic cup (see the attached video).

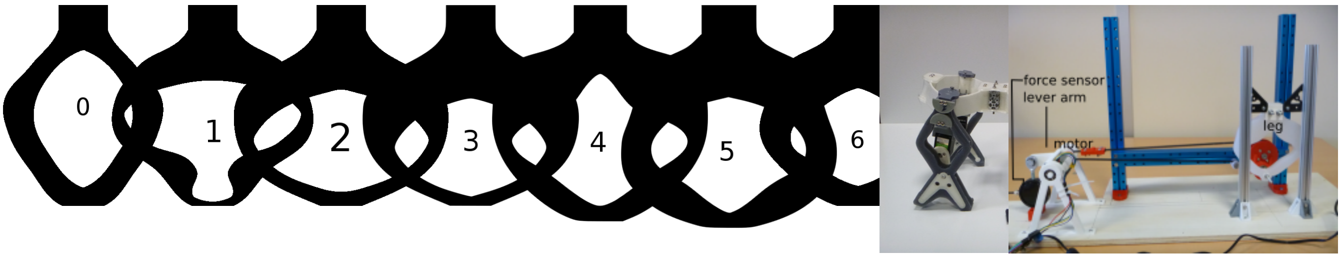

Figure 4. Initial shape (labelled 0) for the optimization and different shapes (labelled 1 to 6) obtained by numerical experiments. Pictures represents the robot with the legs and the test best that has been used to verify the accuracy of the simulation

7.3. Modeling Novel Soft Mechanosensors based on Air-Flow Measurements

In this work, we introduce a new pneumatic mechanosensor dedicated to Soft Robotics and propose a generic method to reconstruct the magnitude of a contact-force acting on it. This is illustrated by Fig. 5. Changes in cavity volumes inside a soft silicon pad are measured by air-flow sensors. The resulting mechanosensor is characterized by its high sensitivity, repeatability, dynamic range and accurate localization capability in 2D. Using a regression found by machine learning techniques we can predict the contact location and force magnitude accurately when the force magnitudes are within the range of the training data. To be able to provide a more general model, a novel approach based on a Finite Element Method (FEM) is introduced. We formulate an optimization problem, which yields the contact load that best explains the observed changes in cavity volumes. This method makes no assumptions on the force range, the shape of the soft pad or the shape of its cavities. The prediction of the force also results in a model for the deformation of the soft pad. We characterize our sensor and evaluate two designs, a soft pad and a kidney-shaped sensor, in different scenarios. A paper was accepted for the journal *Robotics and Automation Letters (RA-L)* [5]. Furthermore, an extended abstract was accepted at the *RoboTac 2019 Workshop* at *IROS 2019*, leading to a presentation of a demo of the proposed technology.

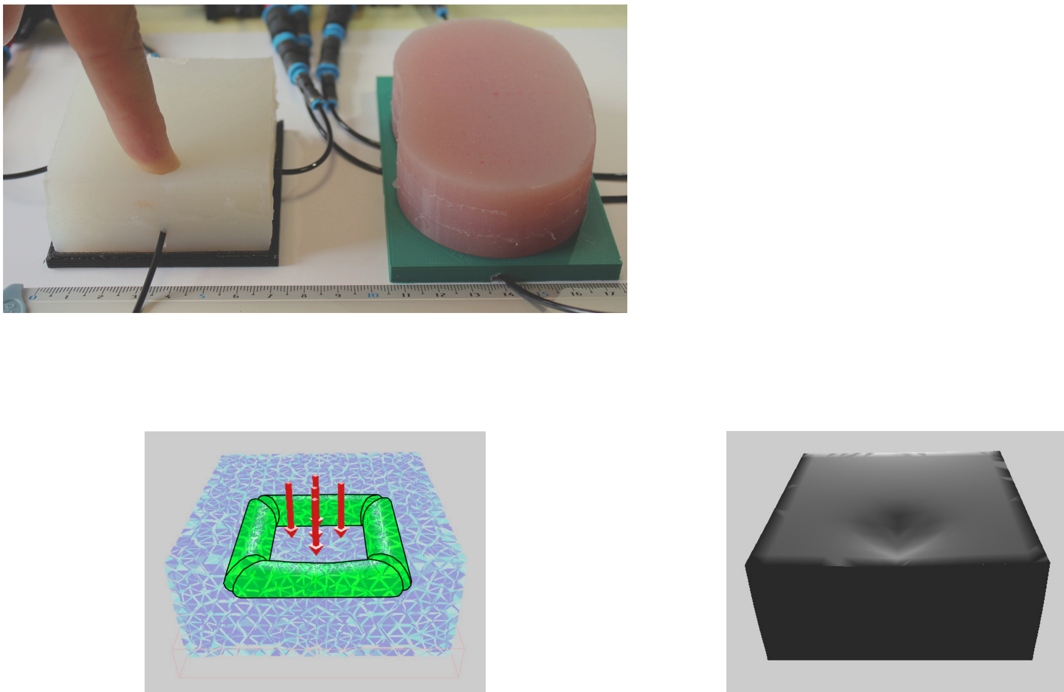

Figure 5. In this work, we show two designs of a novel soft mechanosensor made out of silicone (top, a soft pad and a kidney). When an external force is applied, the volume of cavities embedded in the silicone changes (left). This change in volume is registered through air-flow sensors. Using machine learning and FEM-based techniques, we show that it is possible to estimate the location and magnitude of an external force on the mechanosensor. Using the FEM also yields an estimation of the deformation of the sensor (left and right).

7.4. Calibration and External Force Sensing for Soft Robots using an RGB-D Camera

Benefiting from the deformability of soft robots, calibration and force sensing for soft robots are possible using an external vision-based system, instead of embedded mechatronic force sensors. In this work, we first propose a calibration method to calibrate both the sensor-robot coordinate system and the actuator inputs. This task is addressed through a sequential optimization problem for both variables. We also introduce an external force sensing system based on a real-time Finite Element (FE) model with the assumption of static configurations, and which consists of two steps: force location detection and force intensity computation. The algorithm that estimates force location relies on the segmentation of the point cloud acquired by an RGB-D camera. Then, the force intensities can be computed by solving an inverse quasi-static problem based on matching the FE model with the point cloud of the soft robot. As for validation, the proposed strategies for calibration and force sensing have been tested using a parallel soft robot driven by four cables (see figure 6 and reference [18]).

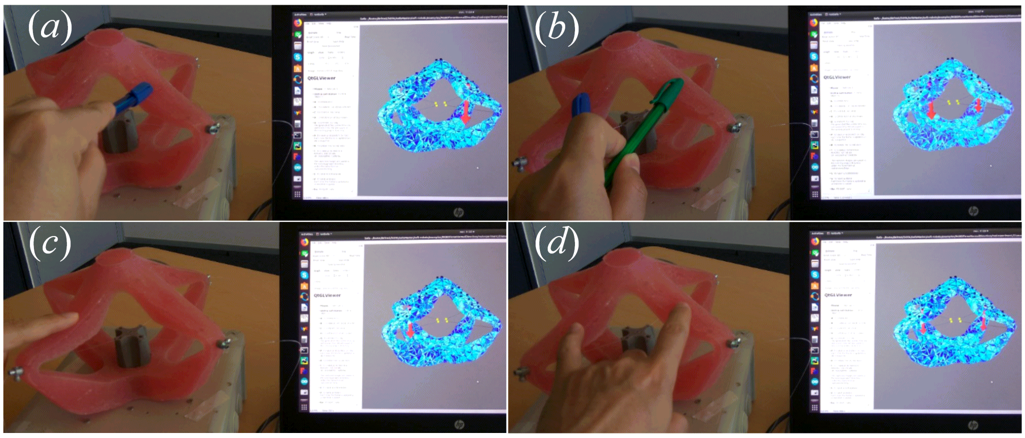

Figure 6. Screenshot of external force sensing. The robot has four cables with constant length for the experiment. (a) and (c) show one external force on the actuated soft robot. (b) and (d) show case with two external forces.

7.5. Motion Control of Cable-Driven Continuum Catheter Robot through Contacts

Catheter-based intervention plays an important role in minimally invasive surgery. For the closed-loop control of catheter robot through contacts, the loss of contact sensing along the entire catheter might result in task failure. To deal with this problem, we propose a decoupled motion control strategy which allows to control insertion and bending independently. We model the catheter robot and the contacts using the Finite Element Method. Then, we combine the simulated system and the real system for the closed-loop motion control. The control inputs are computed by solving a quadratic programming (QP) problem with a linear complementarity problem (LCP). A simplified method is proposed to solve this optimization problem by converting it into a standard QP problem. Using the proposed strategy, not only the control inputs but also the contact forces along the entire catheter can be computed without using force sensors. Finally, we validate the proposed methods using both simulation and experiments on a cable-driven continuum catheter robot for the real-time motion control through contacts [17].

7.6. Control Design for Soft Robots based on Reduced Order Model

Inspired by nature, soft robots promise disruptive advances in robotics. Soft robots are naturally compliant and exhibit nonlinear behavior, which makes their study challenging. No unified framework exists to control these

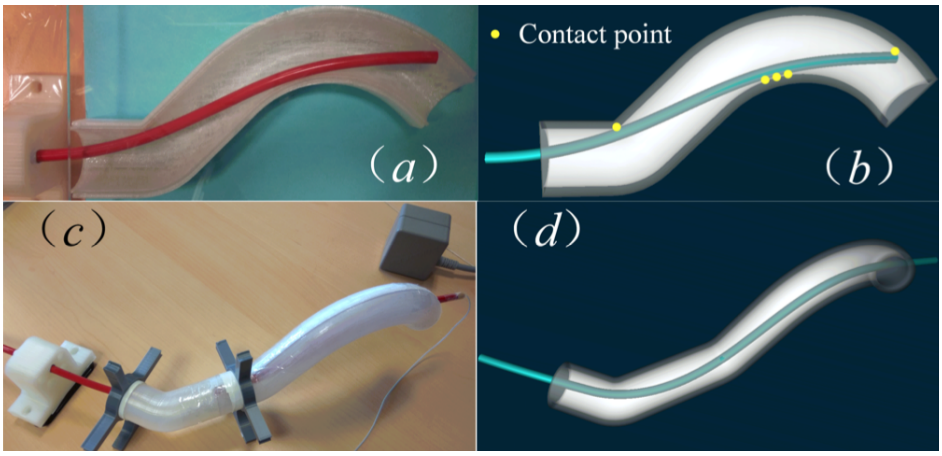

Figure 7. (a) and (c) present experimental setups for the validation. (b) and (d) show that we take into account the contact and provide accurate results in the simulation

robots, especially when considering their dynamics. This work proposes a methodology to study this type of robots around a stable equilibrium point. It can make the robot converge faster and with reduced oscillations to a desired equilibrium state. Using computational mechanics, a large-scale dynamic model of the robot is obtained and model reduction algorithms enable the design of low order controller and observer. A real robot is used to demonstrate the interest of the results [14].

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

We would like to acknowledge FACEBOOK company for the donation of $25,000 for our research (department FACEBOOK Reality Labs).

8.2. Bilateral Grants with Industry

We received an industry grant (CIFRE) with Robocath to work on autonomous catheter navigation. This grant will fund a PhD student for 3 years, starting in February 2019.

We have an ongoing bilateral project with the company InSimo on the simulation of suture.

9. Partnerships and Cooperations

9.1. Regional Initiatives

- **INVENTOR** Innovative tool for soft robot design and its application for surgery. This project is financed by **I-Site ULNE EXPAND**, supported by “le programme d’Investissements d’Avenir” and “la Métropole Européenne de Lille”. The objective of this project is to develop an innovative tool for the facilitation of soft robot design.

- **COMOROS** Control of deformable robots for surgery Duration april 2017 to march 2020 Program: FEDER Coordinator: C. Duriez Abstract: Surgical procedures are often carried out using instruments made of stiff materials that interact with delicate biological tissues such as internal organs, blood vessel walls and small cavities. This incompatibility of stiffness is one of the sources of danger in many surgical procedures. The use of robots made of soft materials, also called soft robots, would limit such risks by reducing contact pressures and stress concentrations. Their intrinsic deformability would also increase the ability to manoeuvre in confined spaces. However, the promising concept of using soft robots for surgical procedures cannot be practically implemented, due to the lack of precise modelling and control methods for soft robots. This scientific obstacle, identified as a pending issue by major surveys in this field, becomes particularly challenging when interacting with an environment as complex as the human anatomy. Drawing on our background in soft tissue simulation, contact models, surgical applications and soft robotics, our ambition in this project is to:
  - Develop accurate and generic numerical methods for continuum mechanics, adapted to strong real-time constraints in order to demonstrate the ability to model soft mechatronics systems.
  - Reconsider parametrization methodologies of digital models of the patient anatomy through the observation of mechanical interactions with soft robots via embedded sensors and medical imaging
  - Rethink motion generation and teleoperation control with force feedback so as to be compatible with the large number of degrees of freedom of soft robots and be based on accurate, rapidly-computed deformable models and interaction models.

  The project also targets the development of software with the required performance and features, as well as the experimental validation of models and methods using prototypes in realistic environments.
- The PhD Thesis of Félix Vanneste is half-funded by the Hauts-de-France region.

9.2. National Initiatives

- **ROBOCOP**: Robotization of Cochlear implant. This is a 4-year project, supported by the ANR (French National Agency for Research) in the framework of PRCE, starting from 1 October 2019 until 30 September 2023. ROBOCOP aims at creating a new prototype of cochlear implant, and robotize (i.e. actuate and control) its insertion process to facilitate the work of surgeon, to increase the success ratio, and to decrease the probability of trauma.
- **SIMILAR** Soft robotIcs framework for modeling, simulation and control. This project is supported by **Inria ADT**, and the objective is to design new 3D interactive software to design soft-robots. This new software will be on the top of our existing software stack relying on SOFA for all numerical simulation aspects and 3D rendering aspects.
- **Tremplin ERC** Christian Duriez received a **ANR** grant “tremplin ERC” (150k€) given the result obtained last year on the ERC proposal (evaluated at “grade A”). The project has allowed to allocate new resources on the developments that were presented in this ERC.

9.3. European Initiatives

9.3.1. Collaborations in European Programs, Except FP7 & H2020

Meichun Lin was doing a project belonged to Interreg - 2 Seas Mers Zeeën on Cooperate Brachytherapy(CoBra), it is a 4 years project which gathers the experts from the countries between English Channel and southern North Sea aiming on finding an advance method for curing prostate cancer. (see more details on https://cobra-2seas.eu/) The project is divided by several fields which are - MR compatible robot design, radiation dose measurement, steerable needle design, mimic soft-tissue (phantom) design and virtual reality real-time training tool development etc. Meichun was working on developing virtual reality real-time training tool with Defrost team. The aim is to have a interactive platform for human and the robot. By using SOFA framework to simulate the soft tissue’s deformation and the interaction with needle insertion under the real-time, also with the Image modelling of MRI and soft-tissue modelling and so on and so forth.

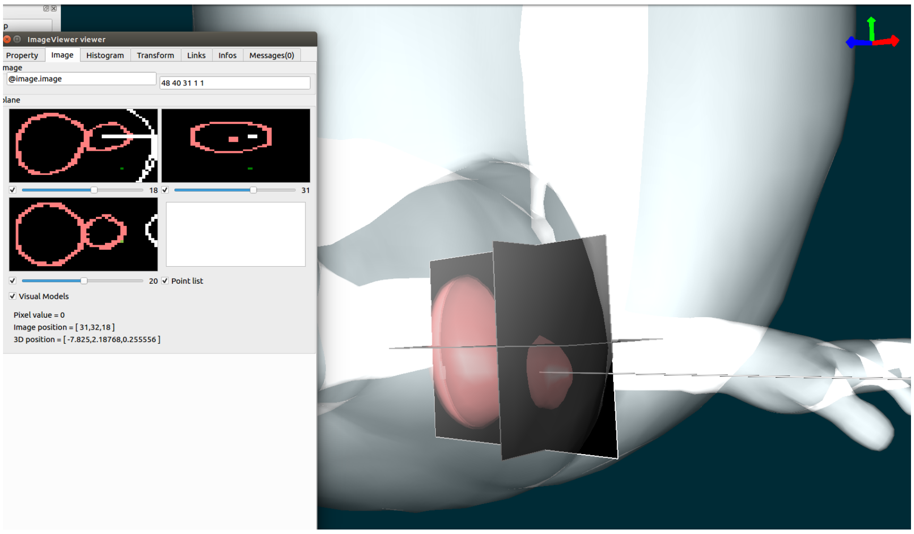

Figure 8. The virtual reality real-time simulation of the CoBra project

9.4. International Initiatives

9.4.1. Inria International Labs

9.4.1.1. AC/DC: A Charm lab / Defrost team Collaboration

Inria@SiliconValley Associate Team
Defrost team (Deformable Robotic Software, Inria Lille – Nord Europe) and the Charm Lab (Collaborative HAptics and Robotics in Medicine Lab, Stanford University, USA) on the topic of soft robots. On this topic, these two entities are very complementary because the Charm Lab is interested in the new design, the realization, the planning and the experimentation and the Defrost team is more centered on mechanical modeling, simulation and the algorithms of control. The collaboration is based on two axes: (1) the creation of flexible robots whose position and rigidity can be controlled, (2) the mechanical modeling and simulation of a robot that navigates in an environment through growth.

- Partner: Allison Okamura at the Department of Mechanical Engineering of Stanford University, USA
- Start year: 2019
- See also: https://team.inria.fr/defrost/collaboration-with-charm-lab-stanford/

9.5. International Research Visitors

9.5.1. Visits of International Scientists

Federico Renda from Khalifa University of Abu Dhabi visited the DEFROST team for a month to work on the implementation of a Cosserat Implementation for Beam simulation in the SOFA framework.

9.5.2. Internships

- Van Pho Nguyen, PhD Candidate from Japan Advanced Institute of Science and Technology (JAIST), visited the team for 6 months to work on the topic of underwater robots.
- Margaret Koehler from the Charm Lab, Stanford University, USA, visited the team for a month to work on the simulation of a soft haptic device.

9.5.3. Visits to International Teams

9.5.3.1. Research Stays Abroad

- Gang Zheng has visited Nanjing University of Science and Technology (China) for 1 month in July 2019.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events: Organisation

10.1.1.1. General Chair, Scientific Chair

- Gang Zheng is member of Bureau ED (Ecole Doctorale) SPI 072 in the domain of AGITSI (Automatique, Génie Informatique Traitement du Signal et des Images), 2020-2024.
- Gang Zheng is member of Bureau Scientifique (ex-BCP) of Inria Lille – Nord Europe, from February 2019.
- Gang Zheng was a vice-chair of the IFAC Technical Committee “Social Impact of Automation”, International Federation of Automatic Control, TC9.2, till 2019
- Gang Zheng is co-chair of the working group “Commande et pilotage en environnement incertain” of GRAISYHM
- Christian Duriez was chair of the workshop “ Modeling, Simulation and Control of Deformable Robots on SOFA Framework” organized during Robosoft Conference 2019 https://team.inria.fr/defrost/software/defrost-platform-modeling-simulation-and-control-of-deformable-robots-on-sofa-framework/

10.1.1.2. Member of the Organizing Committees

- This year, Stefan Escaida Navarro was a Co-Organizer of the *2nd Workshop on Proximity Perception in Robotics* at *IROS 2019* in Macao, China. [1]
- Gang Zheng, Associate Editor, SIAM CT19, Chengdu, China (SIAM Conference of Control & Its Applications 2019)
- Christian Duriez is member of the organizing committee of ICRA 2020 (in Paris), chair of Social Media and Community.

10.1.2. Scientific Events: Selection

10.1.2.1. Member of the Conference Program Committees

- Gang Zheng is IPC member of SIAM19, ICSRT19, ICFCTA19, ICRAI19, AITC19, APCRAS20, ICSRT20, ETFA20, ICSC20.
- Jeremie Dequidt is IPC member of International Symposium on Visual Computing 2019
- Christian Duriez is IPC of Robosoft 2019 and Robosoft 2020

10.1.2.2. Reviewer

Alexandre Kruszewski was revewier for:

- 2020 21st IFAC World Congress
- 2020 3rd IEEE International Conference on Soft Robotics
- 2020 American Control Conference
- 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems
- 2019 IEEE Conference on Decision and Control
- 2019 IEEE International Conference on Fuzzy Systems
- 2019 Chinese Control and Decison Conference

[1] https://www.proxelsandtaxels.org/en/

Olivier Goury was reviewer for:

- 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)
- IEEE International Conference on Soft Robotics (ROBOSOFT 2020)

Stefan Escaida Navarro was reviewer for:

- 2020 IEEE International Conference on Robotics and Automation (ICRA 2020)
- 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019)

Jeremie Dequidt was reviewer for:

- 2019 International Symposium on Visual Computing
- 2020 IEEE Conference on Virtual Reality and 3D User Interfaces
- 2019 IEEE International Conference on Robotics and Automation (ICRA 2019)
- 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019)

Christian Duriez was reviewer for:

- 2019 IEEE International Conference on Robotics and Automation (ICRA 2019)
- 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2019)
- Conference Robotics Science and System (RSS 2019)
- Siggraph Conference 2019

10.1.3. Journal

10.1.3.1. Member of the Editorial Boards

Christian Duriez is associate editor of:

- IEEE Transactions on Haptics
- IEEE Robotics and Automation Letters

10.1.3.2. Reviewer - Reviewing Activities

Olivier Goury was reviewer for:

- ACM CHI Conference on Human Factors in Computing Systems
- International Journal of Robotics Research (IJRR)
- IEEE Robotics and Automation Letters

Stefan Escaida Navarro was reviewer for:

- IEEE Robotics and Automation Letters (RA-L)
- IEEE Sensors Journal

Alexandre Kruszewski was revewier for:

- IEEE Transaction on Fuzzy Systems
- IEEE Robotics and Automation Letters
- IEEE Transactions on Vehicular Technology
- International Journal of Robotics Research
- Systems & Control Letters
- Fuzzy Sets and Systems
- IET Control Theory & Applications

Jeremie Dequidt was reviewer for:

- IEEE Transaction on Haptics
- IEEE Robotics and Automation
- IEEE Robotics and Automation Letters

Christian Duriez was reviewer for:

- Nature Robotics
- International Journal of Robotic Research
- IEEE Robotics and Automation Letters
- IEEE Transactions on Graphics

10.1.4. Invited Talks

Christian Duriez was invited for:

- Keynote at IEEE Robosoft Conference
- Keynote during scientific day of FEMTO (Besançon)
- Keynote & Practice during the 9th Summer School on Surgical Robotics
- Keynote during the FOOR 2019 (Forum Ouvert Oeuvre et Recherche) in Lille

10.1.5. Scientific Expertise

Christian Duriez is expert of the European Community for monitoring the FET project HybridHeart

10.1.6. Research Administration

- Christian Duriez has been nominated Director of the Inria Lille – Nord Europe center for an interim of 3 months (July to September). He is also the president of the “Commission des Emplois de Recherche” (Research Jobs Commission)
- Olivier Goury is an elected member of the “Comité de centre” and a member of the “Comité de développement technologique” (CDT) at Inria Lille – Nord Europe.
- Alexandre Kruszewski is member of the Laboratory council (CRIStAL).
- Damien Marchal is lead of the “Pôle d’Appui au Développement et à la Recherche” of the CRIStAL Laboratory.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Engineering cycle: Walid Amehri, Start & Go Arts et Sciences, 24h, level L3, Centrale Lille.

Engineering cycle: Walid Amehri, Start & Go Conception et Environement, 10h, level L3, Centrale Lille.

Engineering cycle: Walid Amehri, Automatique IE3, 20h, level L3, Centrale Lille.

Engineering cycle: Alexandre Kruszewski, 14 modules (automatic control, numeric control, embeded systems, robotics etc.), ≈250h, level (L3, M1, M2), Centrale Lille

Engineering cycle: Jeremie Dequidt 6 modules (Programming, Software Engineering, Embedded Systems, Databases, Medical Simulation etc.) ≈350h, level (L3, M1, M2), Polytech Lille

Master: Christian Duriez, Soft robotics, 24h, M2, Graduate degree en intelligence artificielle à l’Ecole Polytechnique (Palaiseau)

Master: Christian Duriez, Interactive simulation, 20h, M2, Master Image Visualisation Interaction, Université de Lille

10.2.2. Supervision

PhD: Eulalie Coevoet, Optimization Based Inverse Model of Soft Robots With Contact Handling, Université de Lille, 9/01/2019, C. Duriez

PhD: Zhongkai Zhang, Vision-based calibration, position control and force sensing for soft robots, Université de Lille, 10/01/2019, J. Dequidt, C. Duriez

PhD: Maxime Thieffry, Modélisation et contrôle de robots déformables à grande vitesse, UPHF, 16/10/2019, A. Kruszewski, C. Duriez, T.M. Guerra

PhD in progress: Walid Amehri, Workspace analysis of soft robots, G. Zheng, A. Kruszewski

PhD in progress: Ke Wu, Control of soft robot under constraints, G. Zheng

PhD in progress: Pierre Schegg, Catheter Navigation using Reinforcement Learning, J. Dequidt and C. Duriez

PhD in progress: Félix Vanneste, Design and simulation of Soft Robots made of mesostructured materials, 01/12/2018, C Duriez, O. Goury

10.2.3. Juries

Gang Zheng has participated the following juries of thesis:

- Imen Mrad, Observabilité et inversion à gauche des systèmes dynamiques hybrides, defended at 16/12/2019, Université de Cergy-Pontoise (Reviewer);
- Yanqiao Wei, Non-asymptotic and robust fractional order differentiators using generalized modulating functions, defended at 15/11/2019, INSA Val de Loire (Examinator);
- Saber Laamiri, Commande des systèmes électriques: Machines synchrones et convertisseurs multiniveaux, defended at 27/09/2019, Ecole centrale de Nantes (Examinator).

Christian Duriez was member of the following juries of PhD thesis:

- Margaret Koehler, Model-Based Design And Control Of Deformable Robots And Haptic Devices, Stanford University, USA, defended on the 14th of November 2019 (Reviewer)
- François Schmitt, Méthodes et procédés pour l'assistance à la chirurgie laparoscopique par comanipulation, University of Strasbourg, defended the 30th of September 2019 (Reviewer)
- Quentin Peyron, Concept de robot à tube concentrique magnétique: introduction et analyse, defended the 5th of December 2019 (President of the Jury)

Christian Duriez was member of the following juries for Habilitation thesis:

- Sinan Haliyo, Interactions Multi-Echelles, defended the 6th of December 2019 (Reviewer)
- Guillaume Caron, Vision Robotique Directe, defended the 10th of December 2019 (President of the Jury)

10.3. Popularization

- http://handsonsoftrobotics.lille.inria.fr/
- SIDO 2019: SIDO is leading European Solutions and Technologies event for IoT, Artificial Intelligence and Robotics for strategic decision-makers in innovation and business operations. Jeremie Dequidt has presented current research works arund Soft Roboctics.

10.3.1. Interventions

- Fête de la science 2019: Bruno Carrez and Olivier Goury took part in the " village des sciences" at the "Gare Saint-Sauveur" in Lille city center to present soft robots to several groups of students from middle school and high school which represents about 150 children over 2 days between October 10th and 11th 2019.
- FOSDEM 2019 Brussels: its an open-software manifestation which happen every years during 2 days. Some people of our team (Damiens Marchal, Eulalie Coevoet, Bruno Marques, Bruno Carrez and Félix Vanneste) went there to help the SOFA consortium to make some advertisement of our simulation tools.
- ISN intervention: Olivier Goury presented the field of soft robotics to high school students taking a Computer Science option (Informatiques sciences du numérique) and exchanged about the school projects on March the 20th 2019.

- Défi Robotique at Lycée Baggio: Olivier Goury took part in the Défi Robotique at Lycée Baggio in which teams of middle school, high school, preparatory classes and engineering students have 24 hours to solve a robotics challenge. Olivier Goury gave a conference on Soft Robotics and was a member of jury.
- Journée de la recherche Centrale Lille: Alexandre Kruszewski, Thor Morales-Bieze and Bruno Carrez presented the research activities (with live demos) in a showroom dedicated to the promotion of the scientific activities of the Laboratory of the campus.

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] E. COEVOET. *Optimization-based inverse model of soft robots, with contact handling*, Université de Lille 1, Sciences et Technologies, January 2019, https://hal.archives-ouvertes.fr/tel-02446416

[2] M. THIEFFRY. *Model-Based Dynamic Control of Soft Robots*, Université Polytechnique des Hauts-de-France, October 2019, https://hal.archives-ouvertes.fr/tel-02363267

[3] Z. ZHANG. *Vision-based calibration, position control and force sensing for soft robots*, Université de Lille, January 2019, https://hal.archives-ouvertes.fr/tel-01990867

Articles in International Peer-Reviewed Journals

[4] B.-H. DU, A. POLYAKOV, G. ZHENG, Q. QUAN. *Quadrotor trajectory tracking by using fixed-time differentiator*, in "International Journal of Control", 2019, vol. 2019 - Issue 12 [*DOI :* 10.1080/00207179.2018.1462534], https://hal.inria.fr/hal-01947365

[5] S. ESCAIDA NAVARRO, O. GOURY, G. ZHENG, T. MORALES BIEZE, C. DURIEZ. *Modeling Novel Soft Mechanosensors based on Air-Flow Measurements*, in "IEEE Robotics and Automation Letters", 2019, vol. 4, n° 4, pp. 4338 - 4345 [*DOI :* 10.1109/LRA.2019.2932604], https://hal.inria.fr/hal-02239080

[6] Z. JIANG, O. MAYEUR, J.-F. WITZ, P. LECOMTE-GROSBRAS, J. DEQUIDT, M. COSSON, C. DURIEZ, M. BRIEU. *Virtual image correlation of magnetic resonance images for 3D geometric modelling of pelvic organs*, in "Strain", January 2019, vol. 55, n° 3, e12305 [*DOI :* 10.1111/STR.12305], https://hal.archives-ouvertes.fr/hal-02403391

[7] M. KOEHLER, A. M. OKAMURA, C. DURIEZ. *Stiffness Control of Deformable Robots Using Finite Element Modeling*, in "IEEE Robotics and Automation Letters", April 2019, vol. 4, n° 2, pp. 469-476 [*DOI :* 10.1109/LRA.2019.2890897], https://hal.inria.fr/hal-02079146

[8] S. MAALEJ, A. KRUSZEWSKI, L. BELKOURA. *Derivative-Based Sampled Data Control for Continuous Linear Parameter Varying System With Unknown Parameters*, in "Journal of Dynamic Systems, Measurement, and Control", August 2019, vol. 141, n° 8 [*DOI :* 10.1115/1.4042947], https://hal.archives-ouvertes.fr/hal-02403902

[9] M. MBOUP, C. JOIN, M. FLIESS, Y. WANG, G. ZHENG, D. EFIMOV, W. PERRUQUETTI. *Comments on "Differentiator application in altitude control for an indoor blimp robot"*, in "International Journal of Control", 2020, forthcoming [*DOI :* 10.1080/00207179.2018.1500040], https://hal.inria.fr/hal-01832874

[10] J. REN, L. YU, C. LYU, G. ZHENG, H. SUN, J.-P. BARBOT. *Dynamical Sparse Signal Recovery with Fixed-Time Convergence*, in "Signal Processing", 2019, vol. 162, pp. 65-74, https://hal.inria.fr/hal-02406715

[11] C. ROGNON, M. KOEHLER, C. DURIEZ, D. FLOREANO, A. M. OKAMURA. *Soft Haptic Device to Render the Sensation of Flying Like a Drone*, in "IEEE Robotics and Automation Letters", July 2019, vol. 4, n^{o} 3, pp. 2524-2531 [*DOI :* 10.1109/LRA.2019.2907432], https://hal.archives-ouvertes.fr/hal-02400542

[12] W. SAADI, D. BOUTAT, G. ZHENG, L. SBITA, L. YU. *Algorithm to compute nonlinear partial observer normal form with multiple outputs*, in "IEEE Transactions on Automatic Control", 2019, forthcoming, https://hal.inria.fr/hal-02406825

[13] C. SONG, H. WANG, Y. TIAN, G. ZHENG. *Event-triggered observer design for delayed output-sampled systems*, in "IEEE Transactions on Automatic Control", 2019, forthcoming, https://hal.inria.fr/hal-02406816

[14] M. THIEFFRY, A. KRUSZEWSKI, C. DURIEZ, T.-M. GUERRA. *Control Design for Soft Robots based on Reduced Order Model*, in "IEEE Robotics and Automation Letters", January 2019, vol. 4, n^{o} 1, pp. 25-32 [*DOI :* 10.1109/LRA.2018.2876734], https://hal.archives-ouvertes.fr/hal-01901031

[15] M. THIEFFRY, A. KRUSZEWSKI, T.-M. GUERRA, C. DURIEZ. *Trajectory Tracking Control Design for Large-Scale Linear Dynamical Systems With Applications to Soft Robotics*, in "IEEE Transactions on Control Systems Technology", 2019, pp. 1-11, forthcoming [*DOI :* 10.1109/TCST.2019.2953624], https://hal.archives-ouvertes.fr/hal-02404003

[16] Y. WANG, G. ZHENG, D. EFIMOV, W. PERRUQUETTI. *Disturbance Compensation Based Controller for an Indoor Blimp Robot*, in "Robotics and Autonomous Systems", 2019, forthcoming, https://hal.inria.fr/hal-02406793

[17] Z. ZHANG, J. DEQUIDT, J. BACK, H. LIU, C. DURIEZ. *Motion Control of Cable-Driven Continuum Catheter Robot through Contacts*, in "IEEE Robotics and Automation Letters", February 2019, vol. 4, n^{o} 2, pp. 1852-1859 [*DOI :* 10.1109/LRA.2019.2898047], https://hal.archives-ouvertes.fr/hal-02052637

[18] Z. ZHANG, A. PETIT, J. DEQUIDT, C. DURIEZ. *Calibration and External Force Sensing for Soft Robots using an RGB-D Camera*, in "IEEE Robotics and Automation Letters", March 2019, vol. 4, n^{o} 3, pp. 2356 - 2363 [*DOI :* 10.1109/LRA.2019.2903356], https://hal.archives-ouvertes.fr/hal-02060976

[19] G. ZHENG, H. WANG. *Finite-time estimation for linear time-delay systems via homogeneous method*, in "International Journal of Control", 2019, vol. 92, n^{o} 6, pp. 1252–1263 [*DOI :* 10.1080/00207179.2017.1390255], https://hal.inria.fr/hal-01649434

[20] G. ZHENG, Y. ZHOU, M. JU. *Robust control of a silicone soft robot using neural networks*, in "ISA Transactions", 2019, forthcoming, https://hal.inria.fr/hal-02406765

International Conferences with Proceedings

[21] F. J. BEJARANO, R. USHIROBIRA, G. ZHENG. *On the observability and detectability of non-commensurate time-delay linear systems*, in "2019 18th European Control Conference (ECC)", Naples, Italy, IEEE, June 2019, pp. 2921-2925 [*DOI :* 10.23919/ECC.2019.8796285], https://hal.inria.fr/hal-02406860

[22] E. COEVOET, A. ESCANDE, C. DURIEZ. *Soft robots locomotion and manipulation control using FEM simulation and quadratic programming*, in "RoboSoft 2019 - IEEE International Conference on Soft Robotics", Seoul, South Korea, April 2019, https://hal.inria.fr/hal-02079151

[23] S. WANG, A. POLYAKOV, G. ZHENG. *Quadrotor Control Design under Time and State Constraints: Implicit Lyapunov Function Approach*, in "ECC'19 - European Control Conference", Naples, Italy, June 2019, https://hal.inria.fr/hal-02093641

[24] Y. WANG, G. ZHENG, D. EFIMOV, W. PERRUQUETTI. *Disturbance Compensation Based Control for an Indoor Blimp Robot*, in "2019 International Conference on Robotics and Automation (ICRA)", Montreal, Canada, IEEE, May 2019, pp. 2040-2046 [*DOI :* 10.1109/ICRA.2019.8793535], https://hal.inria.fr/hal-02406847

[25] Y. ZHOU, M. JU, G. ZHENG. *Closed-loop control of soft robot based on machine learning*, in "2019 Chinese Control Conference (CCC)", Guangzhou, France, IEEE, July 2019, pp. 4543-4547 [*DOI :* 10.23919/CHICC.2019.8866257], https://hal.inria.fr/hal-02406854

Conferences without Proceedings

[26] A. BERNARDIN, C. DURIEZ, M. MARCHAL. *An Interactive Physically-based Model for Active Suction Phenomenon Simulation*, in "SWS19 - SOFA Week Symposium", Paris, France, November 2019, https://hal.inria.fr/hal-02419381

[27] R. K. KATZSCHMANN, M. THIEFFRY, O. GOURY, A. KRUSZEWSKI, T.-M. GUERRA, C. DURIEZ, D. RUS. *Dynamically Closed-Loop Controlled Soft Robotic Arm using a Reduced Order Finite Element Model with State Observer*, in "IEEE 2019 International Conference on Soft Robotics", Séoul, South Korea, April 2019, https://hal.archives-ouvertes.fr/hal-02078809

[28] S. MAALEJ, A. KRUSZEWSKI, L. BELKOURA. *Model-free control of LTI systems: An algebraic state estimation approach*, in "2017 18th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)", Monastir, Tunisia, IEEE, August 2019, vol. 141, n^o 8, pp. 30-35 [*DOI :* 10.1109/STA.2017.8314951], https://hal.archives-ouvertes.fr/hal-02403910

[29] T. MORZADEC, D. MARCHAL, C. DURIEZ. *Toward Shape Optimization of Soft Robots*, in "RoboSoft 2019 - IEEE International Conference on Soft Robotics", Séoul, South Korea, April 2019, https://hal.archives-ouvertes.fr/hal-02078776

[30] G. ZHENG, O. GOURY, M. THIEFFRY, A. KRUSZEWSKI, C. DURIEZ. *Controllability pre-verification of silicone soft robots based on finite-element method*, in "2019 International Conference on Robotics and Automation (ICRA)", Montreal, Canada, IEEE, May 2019, pp. 7395-7400 [*DOI :* 10.1109/ICRA.2019.8794370], https://hal.archives-ouvertes.fr/hal-02403899

Other Publications

[31] R. DAGHER, G. ZHENG, A. QUADRAT. *General closed-form solutions of the position self-calibration problem*, October 2019, Paper under submission, https://hal.inria.fr/hal-02419854