CONTROL and SCIENTIFIC COMPUTING

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Book of abstracts

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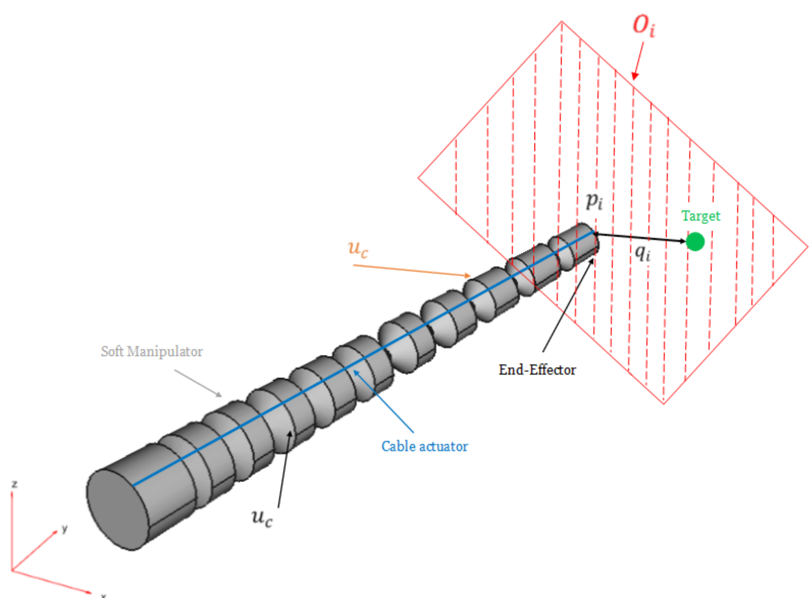
Centrale Lille, Villeneuve d'Ascq, France

SURNAME, Name: AMEHRI, Walid
Team: DEFROST
Thesis title: *Soft Robots Design*
Funded by: I-SITE ULNE
Supervisor(s): GANG Zheng, KRUSZEWSKI Alexandre

Subject:

Given a configuration of silicone soft robot, with the bounded installed actuators, this thesis investigates the operational space estimation for certain chosen points of interest for such a soft robot. For this, finite Element method and Euler-Lagrange method are used to deduce the mathematical model of soft robots, based on which an interval analysis is performed to estimate the operational space. Numerical simulations are provided to highlight the feasibility of the proposed methodology.



SURNAME, Name:	BRAIDIZ, Youness
Team:	SHOC / VALSE
Thesis title:	*Finite-time stability and stabilization of interconnected systems.*
Funded by:	ANR 15 CE23 0007 (Project Finite4SoS), the Government of Russian Federation (Grant 08-08) and the Ministry of Education and Science of Russian Federation (Project 14.Z50.31.0031)
Supervisor(s):	Wilfrid PERRUQUETTI, Denis EFIMOV and Andrey POLYAKOV

Subject:

This thesis is based on the study of finite-time stability of interconnected systems by developing a new framework to address control and estimation issue of this class of systems. Many researchers have been focused on asymptotic or exponential stability of interconnected systems. Also, many results are achieved in the stability analysis of interconnected systems and have been limited to some classes of dynamical systems. For example, the string stability in Swaroop (1996) was described with linear interconnection. The studying of the concept of FTS of interconnected systems could be held by using the Lyapunov analysis, which become an important way to study the behaviour of solutions of the dynamical systems without know it. Many researchers work on the construction of such a function. This was shown for some particular systems, but until now there is not a general method which may allow us to find such a function. Homogeneity theory will also be used in this work, because it is the main tool for achieving the finite-time property for both convergence and input-to-state stability for each class of systems. One of the gaols of this thesis is to develop the finite-time concepts and their characterization and finite-time control and estimation algorithms for oridnary differential equations ODE, differential Inclusion DI, Time Delay Systems TDS and Partial Differential Equations PDE. The research will focus on interconnection of different mathematical models (ordinary differential equations, differential inclusions, time delay systems, partial differential equations).

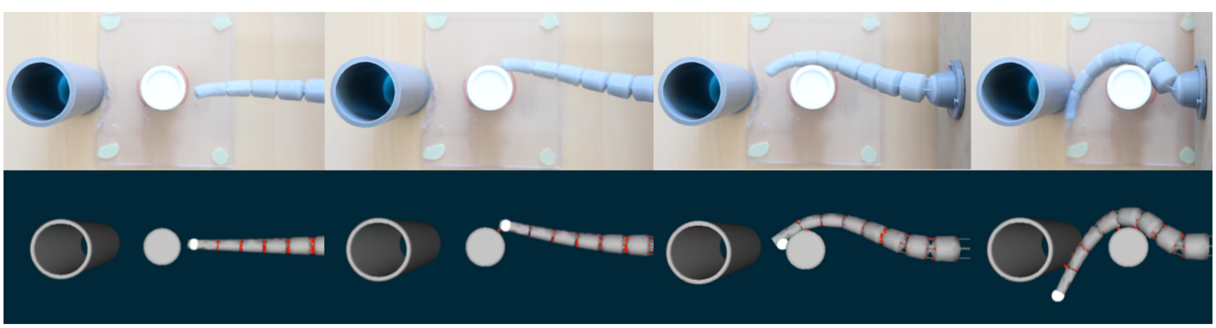
SURNAME, Name: COEVOET Eulalie
Team: DEFROST
Thesis title: *Optimization-based inverse model of soft robots with contact handling.*
Funded by: INRIA Lille
Supervisor(s): Christian DURIEZ

Subject:

Soft robotics draws its inspiration from nature, from the way living organisms move and adapt their shape to their environment. In opposition to traditional rigid robots, soft robots are built from highly compliant materials, allowing them to accomplish tasks with more flexibility and adaptability. They are safer when working in fragile environment. They have the advantages of producing low forces that are suitable for manipulating/interacting with sensitive objects/surroundings without harming them. These characteristics allow for potential use of soft robotics in the fields of manufacturing and medicine. But the field of soft robotics brings new challenges, in particular for modeling and control.

Within this thesis we aim at providing generic methods for soft robot modeling, without assumptions on the geometry. The methods are based on the finite element method to capture the deformations of the robot's structure and of its environment when deformable. We formulate the problem of their inverse kinematics and dynamics as optimization programs, allowing easy handling of constraints on actuation and singularity problems. We are able to control several types of actuation, such as cable, pneumatic and hydraulic actuations.

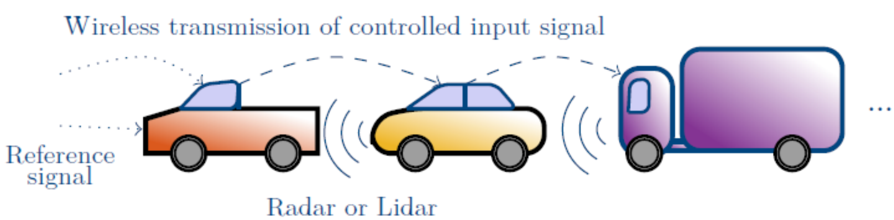
Moreover, most of the applications involve interaction of the robot with obstacles. Yet soft robots kinematics is highly dependent on environmental factors. We propose new methods that include contacts into the optimization process. These methods make an important step as we think that the knowledge of contacts in the modeling is all the more important. Finally, we propose to control some soft robots during locomotion and grasping tasks which require the use of contact with static friction. We give a particular attention to provide solutions with real-time performance, allowing online control in evolving environments.



SURNAME, Name: DILEEP, Deesh
Team: SHOC/VALSE
Thesis title: *Network Design for Decentralized Control*
Funded by: UCoCoS project, Marie Skłodowska-Curie Actions, H2020 programme
Supervisor(s): L. HETEL, J.P. RICHARD, W. MICHIELS

Subject:

A general approach is proposed to design decentralized, distributed, or overlapping fixed-order controllers for multiple input multiple output plants with time-delays by considering them as special cases of structured controllers. This is done by introducing structural constraints within the optimization problem for tuning the controller parameters. However, this approach did not exploit the structure of the controller or system while computing the objective functions, thereby leading to a negligible reduction in computational complexity. As a next step, a structure exploiting method is proposed for the design of controllers for a special class of multiple input multiple output systems with time-delays. The systems considered are delay coupled identical systems arranged in some network structure, which are to be controlled by identical fixed-order decentralized, distributed, or overlapping controllers. By using our approach, we improve the computational efficiency for controller design with the number of subsystems. This structure exploiting method reduces the overall design problem to a robust/simultaneous controller design problem for one parameterized subsystem, where the allowable values of the parameter correspond to eigenvalues of the adjacency matrix of the network graph. We suggest treating these eigenvalues as perturbations, contained in specific intervals or regions in the complex plane determined by the topology of the network. By optimizing the corresponding pseudospectral abscissa using a novel structure exploiting algorithm, we ensure that the achieved stability property, and the computational complexity of the controller design, are independent of the number of (identical) subsystems. An application of automated heterogeneous (parameter) vehicular platoon using Cooperative Adaptive Cruise Control (CACC) is also considered. The corresponding controllers are designed using our framework. The predecessor-follower topology (see Fig. 1. below) of the CACC platoon is again exploited to ensure that the overall computational complexity (for designing controllers) are independent of the number and combination of vehicles in the platoon.



The predecessor-follower topology of CACC considered in this work.

SURNAME, Name: DOS REIS DE SOUZA, Alex
Team: VALSE
Thesis title: *Estimation and Control Methods for Microbial Communities*
Funded by: IPL COSY
Supervisor(s): EFIMOV Denis,
POLYAKOV Andrey
GOUZÉ Jean-Luc (Inria Sophia Antipolis)

Subject:

In modern and practical biotechnological and biochemical applications, bioreactors are widely known for allowing experiments involving living microorganisms, under controlled conditions and that mimics a natural environment. Many applications arise from such experiments, like pharmaceutical production, yeast fermentation, ethanol production, polymerization and many others. A bioreactor might operate in three distinct modes: batch, fed-batch and continuous. In the first, media is added and the process allowed to proceed until a certain condition is reached, in the second fresh media can be continuously fed into the bioreactor but not removed and, finally, the third comprehends the case in which fresh media might be added and removed proportionally. A well-known example of continuous bioreactor is the chemostat.

The issue of monitoring the processes variables inside a bioreactor arises as an important question. In fact, for some applications it is crucial to have real-time information about variables such as concentration of biomass, dissolved products or reactants, gaseous outflows or growth, death and production rates of living organisms. The main difficulties are originated by the lack of available sensors for such variables, their cost, their physical set-up or even their sampling time of measurements.

In terms of control, the main interest is to assure permanence of all species, i.e., preventing them to be extinct. Nevertheless, the principle of competitive exclusion – a well-known result in synthetic biology – states that, in the competition for a single nutrient, at most one species survive. Clearly, this is not what is observed in nature, where multiple species might survive at the same time in a given environment. The design objective, then, is to overcome this drawback and allow experiments to mimic natural conditions or to obtain a specific community behavior.

The major difficulties on control/observer design for biological processes come from uncertainties in the available non-linear models and their observability/observability conditions evaluation, which might not be a trivial task. These issues are directly related on how well known the dynamics are.

SURNAME, Name: DE FIGUEIREDO BARROSO, Nelson
Team: VALSE
Thesis title: *Coastal waters quality surveillance using bivalves mollusk-based sensors*
Funded by: Région Hauts-de-France and Agence Nationale de la Recherche - ANR
Supervisor(s): EFIMOV, Denis and USHIROBIRA, Rosane

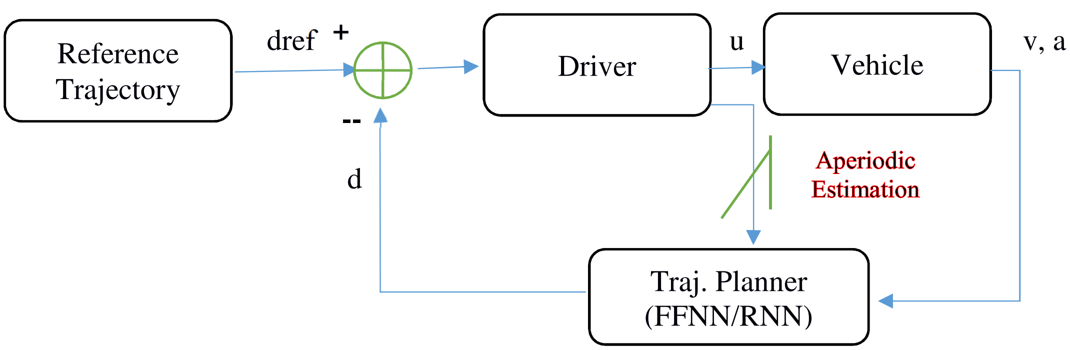
Subject:

This Ph.D. project is a part of an interdisciplinary and collaborative ANR project called WaQMoS, between EA team from CNRS UMR 5805 EPOC, Arcachon, and Valse team from Inria Lille. It is known that marine wildlife may react quite rapidly to changes in its environment, thus, it is expected that its behavioral and physiological responses to pollution and climate changes can be used for ecological monitoring. In this sense, a biosensor monitoring system has been developed based on high-frequency noninvasive valvometry technology (HFNI). This device is strongly based on bivalve's respiratory physiology and ethology, and exploits the timing and characteristics of opening and closing activities of bivalves which are heavily influenced by cyclic environmental changes, internal rhythms, and external variables. Therefore, the main idea is to use the valvometry as an index of clam welfare to evaluate physiological reaction of these animals to environment. However, to give meaning to the measured signals, it is necessary to explore the information contained on it, taking into account a set of entraining variables. Therefore, we aim to develop, by means of systems and control theory methods, a set of input-output models that represent the main characteristic of the process, and from them to develop appropriate algorithms for monitoring, fault detection, and estimates.

Biological rhythms are a fundamental property of life because most of our metabolic, physiological or behavioral activities are rhythmic and controlled in such a way as to assure an optimum fitness between organism and the environment. Consequently, any disruption of these biological rhythms can lead to a reduction of organism fitness and a decrease of ecosystem stability with a loss of its biodiversity. Several ecosystems have been shown to possess two or more alternative states. Following this idea, a complementary route to this thesis is related to the study of robust stability of systems with multiple invariant sets by means of input-to-state stability (ISS) theory. The multistability phenomenon arises when it is necessary to analyze the behavior of a system globally, taking into account all its possible final states and motions. Such a phenomenon is present in many areas including biological, ecosystems, and climate dynamics, being consistent with the aforementioned framework.

SURNAME, Name: JAIN, Ayush Kumar
Team: SHOC (CRIStAL) and SIC (LAMIH)
Thesis title: *Heterogeneous aperiodic models for driver state diagnosis*
Funded by: CNRS Research Federation on Terrestrial Transport and Mobility (FR TTM)
Supervisor(s): Christophe FITER, Philippe POLET, Denis BERDJAG.

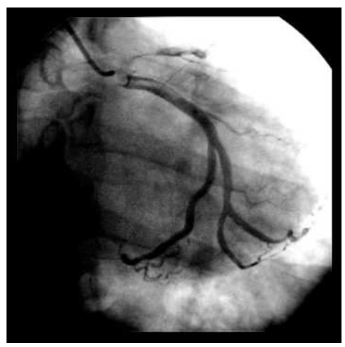
Subject: Advanced Driver Assistance System (ADAS) is meant to help the vehicle drivers. The Trajectory Planner in ADAS guides the driver to maintain a level of velocity (v) and acceleration (a) to go from point A to point B, by considering various factors as fuel efficiency, road terrain, traffic and also attentive/inattentive state of the driver. Sometimes due to bad lighting conditions/bad driver position/faulty sensor, information about driver's attention state is unavailable. The importance of information about the driver in trajectory planning led us to investigate models for the Trajectory Planner which could suggest velocity/acceleration even at aperiodic unavailability of state of the driver. In literature, driver's state diagnosis is done in various ways as Eye/Pose Tracking or Steer wheel pressure tracking. But the algorithms used for such detection and indication are complex and need a lot of online computational power, which is usually not available on board. Also the cost of such ADAS-equipped cars get higher. The objective of this work is to approximate these complex algorithms in the control loop to facilitate the implementation. The effect would be a low-cost implementation and improved market penetration. As a possible solution to this problem, we are proposing Neural Network (NN)-based trajectory generation. The NN will take into consideration, among various other parameters, also the state of the driver. The trajectories will be generated in accordance with a reference trajectory. To start with, the planner is modelled as Feed Forward Neural Network (FFNN) and will extend the work to Recurrent Neural Network (RNN). In addition to designing the planner, stability of such NN-based control needs to be ascertained. For the stability problem, the system consisting of the driver and the vehicle in open-loop is considered as a sampled-data system. In literature, various sampled-data system modelling approaches have been proposed. The one which is used here is the input delay approach. In order to reduce the computational load, the trajectory planner will receive aperiodic assessments of driver's level of attention, leading to adjustments to the planner for future trajectories. The stability of such aperiodic event controlled, input delay modelled systems is given in terms of LMI conditions derived from time-dependent Lyapunov stabilization criteria such as Lyapunov-Krasovskii's Functionals (LKF). The criteria ensure that the planner takes in account the time-varying delay in driver's parameters update, and makes it possible to determine the maximum allowable delay before loss of guaranteed stability.



SURNAME, Name: SCHEGG Pierre
Team: DEFROST / SequeL (DATING)
Thesis title: *Automated control of a robot for catheter navigation in cardiac surgery*
Funded by: CIFRE Grant (Robocath)
Supervisor(s): Christian DURIEZ (DEFROST),
Jérémie DEQUIDT (DEFROST),
Philippe PREUX (SequeL),
Bruno FOURINIER (Robocath)

Subject:

Robocath developped a robot capable of handling catheters and guidewires for Percutaneous Coronary Interventions (PCI). Using the robot, the surgeon can operate from several meters away from the patient, and thus avoid being constantly in the scope of the X rays. Real time X ray imagery is needed to get visual feedback of the catheter inside the blood vessels, but X rays are very dangerous for the surgeons who are exposed to large doses.



As of now the robot is tele-operated, which allows better precision compared to a manual procedure, but still requires great skill and training from the surgeon.

The goal of this thesis is to automate the control of the catheter navigation to perform a PCI. We will first train different learning algorithms (Supervized and Reinforcement Learning) on a custom simulation of the catheter and the arteries based on SOFA. We will then transfer what we learned to the physical robot navigating a catheter in a phantom of the vascular system. We also would like to incorporate video feedback and joystick commands of surgeons in real operations realized with the robot. Finally we hope to be able to apply all of this to perform a fully autonomous navigation to the target zone in an animal.

SURNAME, Name: THIEFFRY, Maxime
Team: DEFROST
Thesis title: *Dynamic Control of Soft Robots*
Funded by: Univ. Lille & FR TTM
Keywords: Robust Control, Large Scale Systems, Model Reduction, Soft Robots
Supervisors: KRUSZEWSKI, Alexandre,
GUERRA, Thierry-Marie (LAMIH)
DURIEZ, Christian

Subject:

Soft robots are made of complex deformable structures with designs often inspired by the organic materials we can find in the nature. They present several advantages over their rigid counterparts, such as being more flexible and compliant to the environment, that makes them inherently safer for human-robot interaction. The use of soft robots is a new way to build robotic systems that can deal with uncertainty and dynamic environments.

At the same time, classical control tools used to work with rigid bodies are not suitable anymore. In contrast to rigid ones, soft robots have a theoretical infinite number of degrees of freedom. In practice we use numerical methods, such as the finite element method (FEM), to model these soft robots. This method requires a spatial discretization of the structure and, for the model to be precise, it requires a huge number of state variables. Moreover, soft robots are highly nonlinear systems and the sensitivity of the materials can easily cause a change in the dynamics of the system.

In this work, we present new methods to control this new type of robots. We use the FEM method to build a large-scale model of the structure studied. Then, model order reduction algorithms provide us with a reduced order system that is used to design a low order observer-based output feedback controller. The objective of this work is to apply this reduced order controller on the full order system, this is why we study the modeling errors brought by the reduction step to build a robust control law. To achieve this objective, we solve a set of Linear Matrix Inequality (LMI) problems to tune the dynamics of the low order systems while proving the stability of the full order model.

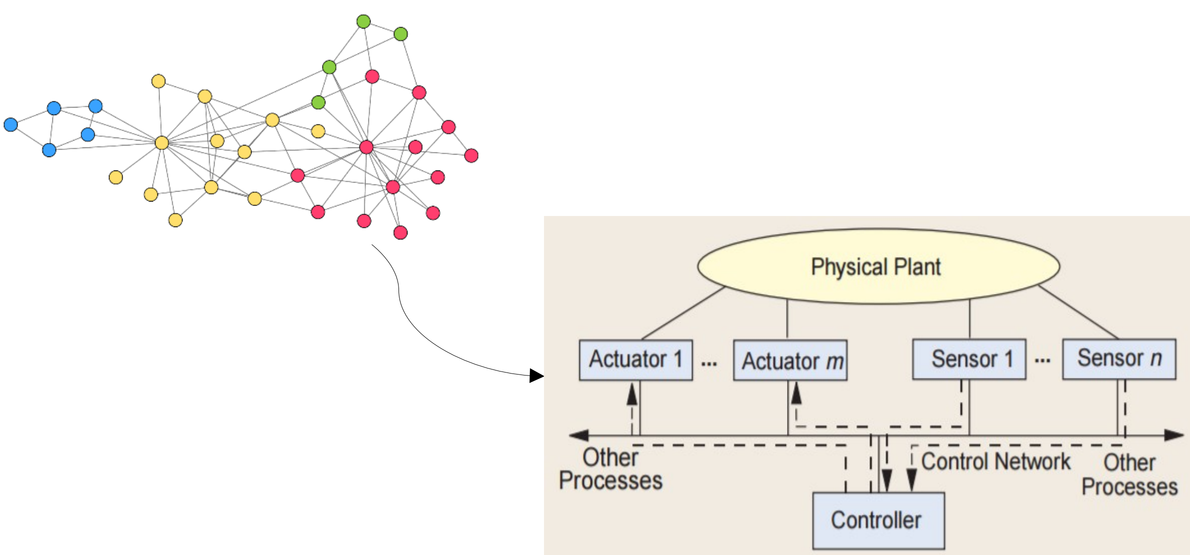
SURNAME, Name: THOMAS, Jijju
Team: SHOC/VALSE
Thesis title: *Networks with Event Triggered Computing*
Funded by: Project UCoCoS
(EU Horizon 2020)
Supervisor(s): Laurentiu HETEL, Christophe FITER,
Jean-Pierre RICHARD, Nathan van de WOUW

Subject:

The main objective of the project is to study the interaction in large networks of nonlinear dynamical systems. We will consider the synchronization of some of the dynamic elements constituting a large network, the communication cost of which needs to be taken into account. Most of the existing methodologies assume a continuous communication link among various linear elements of the network. This is not fully realistic for two reasons:

1. Most of the physical systems are not linear (power converter models, multi agent systems, electrical distribution grids, aircraft dynamics, etc.)
2. Data communication over networks is associated with energy consumption and usage of computation resources as well as communication bandwidth. Given the constraints in terms of all three resources, it is important to consider both control aspects (achieving synchronization) and communication aspects (sampling and hold, delays, etc.) in one approach. A practical scenario would take into account the lack of data communication at all times, thereby implying that considering a digital communication link, which transmits sampled data, is more realistic.

A more realistic representation should consider nonlinear elements and communication graphs with time-varying densities. Here, strong density in a link would represent a frequent/immediate communication, while low density reflects a seldom/delayed one (“delayed” in the sense that data packets can take a longer path through multiple elements chosen for their higher energetic autonomy). We also intend to design scheduling elements deciding the \density" of each link. For instance, an event-triggered strategy according to the subsystem state can be less consuming and perform as well as a periodic, time-driven one. The resulting challenge lies in dynamically optimizing the communication sequences of each link to ensure some desired fast/robust synchronizing control, while taking into account the costs in terms of computational load and/or energy consumption. To sum up in a simple way, the important question is: “How do we choose not only the value of control actions (according to the available sensor data) but also the right moment when information exchange is needed?".



SURNAME, Name: VANNESTE, Félix
Team: DEFROST

Thesis title: *Design and simulation of Soft Robots made of meso-structured materials*
Keywords: Soft robotics, Finite Element Method, Meta-materials, Additive manufacturing

Funded by: INRIA
Supervisor(s): Olivier GOURY, Christian DURIEZ

Subject:

Soft robotics is a new development in robotics where robots are made of soft materials, providing them properties of compliance which can have advantages in many applications. The current state of the art for building soft-robots is to 3D-print a mold in which the silicone will be casted, thus creating a soft structure of the desired geometry. The amount of control on the resulting material properties is limited to stiffness by varying the type of silicone.

Meta-materials, like meso-structured materials, are materials having a specific micro-structured tile that may be periodic, providing them specific macroscopic mechanical properties. These properties would be interesting to use with soft robots by providing some specific properties such as the anisotropy of being stiffer in one direction.

In the project-team DEFROST, a software dedicated to real-time Finite Element Method (FEM) simulation of soft robots and their environment for design and control is being developed. This software is based on the open source framework SOFA and can handle all kinds of material geometries in interaction with their environment. However, when dealing with meso-tructured materials, using a standard FEM model becomes prohibitively expensive, since the underlying mesh describing the material has to be extremely fine, the size of its elements being linked to the scale of the micro-structure.

The purpose of this thesis is to develop a numerical framework allowing to simulate such microstructured materials and their mechanical behaviour in the open source framework SOFA.

SURNAME, Name: Siyuan WANG
Team: VALSE / DEFROST
Thesis title: *Quadrotor control under state and time constraint*
Funded by: CSC
Supervisor(s): Gang ZHENG, Andrey POLYAKOV

Subject:

Control of quadrotor is an interesting problem that is important for many aeronautical applications. Control of the quadrotor under state constrains is a difficult problem even in some particular cases. In order to satisfy the state constraints, the control method such as backstepping, nested saturation could be applied. Most of the cases considering the state constraints are in the condition of surveillance. The quadrotor system is usually divided into two subsystems, translation and rotation subsystem. The rotation subsystem as an inner loop used PID and the translation subsystem as an outer loop used saturation controller to guarantee the global asymptotic stability with all state constraints satisfied.
Time constraint of quadrotor is also necessary in some special condition, for example in the trajectory tracking, in the formation control of quadrotor for safety reason and collision avoidance. Finite-time stability property is closely related to high order sliding mode control(HOSM). In this project, the feedback gain is solved by a group of LMIs which are established by the state and time constraints. Time constraint is implemented by Implicit Lyapunov function method where the controller designed is a non-linear gain scheduling controller.

SURNAME, Name: WANG, Xinyong
Team: SHOC
Thesis title: *Stabilization of infinite dimensional systems by hybrid control laws*
Funded by: Centrale Lille / Région Hauts de France
Supervisor(s): Laurentiu HETEL, Ying TANG

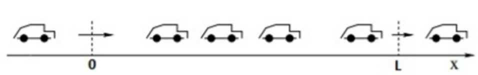
Subject:

The use of digital computers has become a common trend in Cyber-physical systems. In such systems, the computer input signal must be in discrete form. In addition, it needs to be further quantified to be converted into a digital form.

Many studies on stability and control for highly complex dynamic systems have been carried out. Most of the works are dedicated to the finite dimensional systems (described by ordinary differential equations). However, we can frequently encounter physical networks represented by infinite dimensional equations (partial differential equations). Among the different models, we can highlight hydraulic networks, road traffic networks or gas pipeline networks. However, the practical implementation of the controllers results in a numerical realization in the form of an algorithm. This implementation can have a crucial effect under control implementation. For the moment, there are only few research works addressing the numerical implementation of controllers in the systems described by infinite dimensional equations.

In this thesis, I am going to develop new theoretical tools of analysis and control for hybrid systems involving infinite dimensional equations and discontinuous controllers. Two main problems will be studied: (1) stability analysis of the system to ensure some performance criteria. (2) hybrid control design to stabilize the system. Numerical applications to road traffic networks will be subsequently carried out.

Figure: Road traffic



PDE model of traffic flow [Aw and Rascle (2000)]

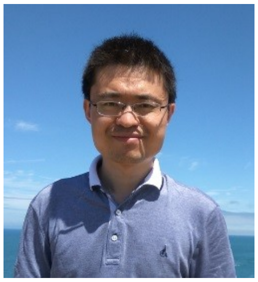
$$\partial_t \rho + \partial_x(\rho V) = 0$$
$$\partial_t(\rho V + \rho P(\rho)) + \partial_x(\rho V^2 + \rho V P(\rho)) + \sigma\rho(V - V_0(\rho)) = 0$$

SURNAME, Name: WANG, Yue
Team: SHOC / VALSE
Thesis title: *Development of a blimp robot for indoor operation*
Funded by: China Scholarship Council
Supervisor(s): Wilfrid PERRUQUETTI, Gang ZHENG, Denis EFIMOV

Subject:

Recently, the blimp robot has attracted more and more attentions of the researchers for its advantages compared to other aircrafts, such as ability for VTOL, stationary and low speed flight, long endurance in air and safe Human-Robot interaction, etc. Therefore, it is an ideal platform for various indoor applications. In this thesis, we study the modeling and motion control of an indoor blimp robot, and develop a real robot for indoor operations such as the long-term surveillance. The work is composed of both theoretical and practical parts. For the theoretical part, first, under reasonable assumptions, the 6-DOF dynamic model is simplified and divided into two independent parts: the altitude motion and the horizontal plane movement. Then, to ensure the accuracy of modeling and control, the nominal model is complemented with disturbance terms which are estimated in real-time and compensated in the designed controllers. Simulations are carried out to verify the performance and robustness of the controllers. For the practical part of the work, based on the functionality analysis of the robot to achieve desired indoor applications, the hardware of the blimp robot is conceived and created. Finally, real tests are made on the blimp robot platform for the validation of the designed motion control laws, and satisfying results are obtained.

SURNAME, Name: ZHANG, Zhongkai
Team: DEFROST
Thesis title: Vision-based Calibration, Position Control and Force Sensing for Soft Robots
Funded by: INRIA & Haut-de-France
Supervisor(s): Jeremie DEQUIDT, Christian DURIEZ



Subject:

Soft robots can interact with the environment in a safe and compliant way because of their deformable structures. However, the modeling of soft robots which have, theoretically, infinite degrees of freedom, are extremely difficult especially when the robots have complex configurations. This difficulty of modeling leads to new challenges for the calibration and the control design of the robots, but also new opportunities with possible new force sensing strategies. This dissertation aims to provide new and general solutions using modeling and vision. The thesis at first presents a discrete-time kinematic model for soft robots based on the real-time Finite Element (FE) method. Then, a vision-based simultaneous calibration of sensor-robot system and actuators is investigated. Two closed-loop position controllers are designed and the robust stability of the closed-loop system is analyzed using Lyapunov stability theory. Besides, to deal with the problem of image feature loss, a switched control strategy is proposed by combining both the open-loop controller and the closed-loop controller. Using soft robot itself as a force sensor is available due to the deformable feature of soft structures. Two methods (marker-based and marker-free) of external force sensing for soft robots are proposed based on the fusion of vision-based measurements and FE model. Using both methods, not only the intensities but also the locations of the external forces can be estimated. The marker-based approach is proposed to find the correct locations of external forces among several possible ones. If there are no obvious feature points on the surface of the soft robot, the marker-free force sensing strategy is available using an RGB-D camera. As a specific application, a cable-driven continuum catheter robot through contacts is modeled based on FE method. Then, the robot is controlled by a decoupled control strategy which allows to control insertion and bending independently. Both the control inputs and the contact forces along the entire catheter can be computed by solving a quadratic programming (QP) problem with a linear complementarity constraint (QPCC). A simplified solution is proposed for the computation of QPCC by converting it into a standard QP problem.