IN PARTNERSHIP WITH:
CNRS

Université de Lorraine

Activity Report 2018

Project-Team SPHINX

Heterogeneous Systems: Inverse Problems, Control and Stabilization, Simulation

IN COLLABORATION WITH: Institut Elie Cartan de Lorraine (IECL)

RESEARCH CENTER
Nancy - Grand Est

THEME
Optimization and control of dynamic systems

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Project-Team SPHINX

Creation of the Team: 2015 January 01, updated into Project-Team: 2016 May 01

Keywords:

Computer Science and Digital Science:

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Other Research Topics and Application Domains:

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1. Team, Visitors, External Collaborators

Research Scientists

Takéo Takahashi [Team leader, Inria, Researcher, HDR]
Ludovick Gagnon [Inria, Researcher, from Sep 2018]
Karim Ramdani [Inria, Senior Researcher, HDR]
Jean-Claude Vivalda [Inria, Senior Researcher, HDR]

Faculty Members

Xavier Antoine [Univ de Lorraine, Professor, HDR]
Thomas Chambrion [Univ de Lorraine, Associate Professor]
David Dos Santos Ferreira [Univ de Lorraine, Associate Professor]
Julien Lequeurre [Univ de Lorraine, Associate Professor]
Alexandre Munnier [Univ de Lorraine, Associate Professor]
Jean-François Scheid [Univ de Lorraine, Associate Professor, HDR]
Julie Valein [Univ de Lorraine, Associate Professor]

Post-Doctoral Fellows

Rémi Buffe [Inria]

Eloise Comte [Inria, from Oct 2018]
Arnab Roy [Inria, from Sep 2018]

PhD Students

Ismail Badia [Inria, from Nov 2018]
Boris Caudron [Thales, until May 2018]
Imene Djebour [Univ de Lorraine]
Alessandro Duca [Univ de Franche-Comté]
Mohamed Id Said [Univ de Lorraine]
Zhanhao Liu [Saint Gobain Recherche, from Oct 2018]
Benjamin Obando [Universidad do Chile, until December 2018]

Administrative Assistant

Céline Cordier [Inria]

2. Overall Objectives

2.1. Overall Objectives

In this project, we investigate theoretical and numerical mathematical issues concerning heterogeneous physical systems. The heterogeneities we consider result from the fact that the studied systems involve subsystems of different physical nature. In this wide class of problems, we study two types of systems: **fluid-structure interaction systems (FSIS)** and **complex wave systems (CWS)**. In both situations, one has to develop specific methods to take the coupling between the subsystems into account.

(FSIS) Fluid-structure interaction systems appear in many applications: medicine (motion of the blood in veins and arteries), biology (animal locomotion in a fluid, such as swimming fishes or flapping birds but also locomotion of microorganisms, such as amoebas), civil engineering (design of bridges or any structure exposed to the wind or the flow of a river), naval architecture (design of boats and submarines, seeking of new propulsion systems for underwater vehicles by imitating the locomotion of aquatic animals). FSIS can be studied by modeling their motions through Partial Differential Equations (PDE) and/or Ordinary Differential Equations (ODE), as is classical in fluid mechanics or in solid mechanics. This leads to the study of difficult nonlinear free boundary problems which have constituted a rich and active domain of research over the last decades.

(CWS) Complex wave systems are involved in a large number of applications in several areas of science and engineering: medicine (breast cancer detection, kidney stone destruction, osteoporosis diagnosis, etc.), telecommunications (in urban or submarine environments, optical fibers, etc.), aeronautics (target detection, aircraft noise reduction, etc.) and, in the longer term, quantum supercomputers. **For direct problems**, most theoretical issues are now widely understood. However, substantial efforts remain to be undertaken concerning the simulation of wave propagation in complex media. Such situations include heterogeneous media with strong local variations of the physical properties (high frequency scattering, multiple scattering media) or quantum fluids (Bose-Einstein condensates). In the first case for instance, the numerical simulation of such direct problems is a hard task, as it generally requires solving ill-conditioned possibly indefinite large size problems, following from space or space-time discretizations of linear or nonlinear evolution PDE set on unbounded domains. **For inverse problems**, many questions are open at both the theoretical (identifiability, stability and robustness, etc.) and practical (reconstruction methods, approximation and convergence analysis, numerical algorithms, etc.) levels.

3. Research Program

3.1. Control and stabilization of heterogeneous systems

Fluid-Structure Interaction Systems (FSIS) are present in many physical problems and applications. Their study involves solving several challenging mathematical problems:

- **Nonlinearity:** One has to deal with a system of nonlinear PDE such as the Navier-Stokes or the Euler systems;
- **Coupling:** The corresponding equations couple two systems of different types and the methods associated with each system need to be suitably combined to solve successfully the full problem;
- **Coordinates:** The equations for the structure are classically written with Lagrangian coordinates whereas the equations for the fluid are written with Eulerian coordinates;
- **Free boundary:** The fluid domain is moving and its motion depends on the motion of the structure. The fluid domain is thus an unknown of the problem and one has to solve a free boundary problem.

In order to control such FSIS systems, one has first to analyze the corresponding system of PDE. The oldest works on FSIS go back to the pioneering contributions of Thomson, Tait and Kirchhoff in the 19th century and Lamb in the 20th century, who considered simplified models (potential fluid or Stokes system). The first mathematical studies in the case of a viscous incompressible fluid modeled by the Navier-Stokes system and a rigid body whose dynamics is modeled by Newton's laws appeared much later [95], [90], [72], and almost all mathematical results on such FSIS have been obtained in the last twenty years.

The most studied FSIS is the problem modeling a **rigid body moving into a viscous incompressible fluid** ([55], [51], [89], [61], [66], [92], [94], [79], [64]). Many other FSIS have been studied as well. Let us mention [81], [69], [65], [54], [44], [60], [45], [62] for different fluids. The case of **deformable structures** has also been considered, either for a fluid inside a moving structure (e.g. blood motion in arteries) or for a moving deformable structure immersed in a fluid (e.g. fish locomotion). The obtained coupled FSIS is a complex system and its study raises several difficulties. The main one comes from the fact that we gather two systems of different nature. Some studies have been performed for approximations of this system: [49], [44], [75], [56], [47]). Without approximations, the only known results [52], [53] is done with very strong assumptions on the regularity of the initial data. Such assumptions are not satisfactory but seem inherent to this coupling between two systems of different natures. In order to study self-propelled motions of structures in a fluid, like fish locomotion, one can assume that the **deformation of the structure is prescribed and known**, whereas its displacement remains unknown ([87]). This permits to start the mathematical study of a challenging problem: understanding the locomotion mechanism of aquatic animals. This is related to control or stabilization problems for FSIS. Some first results in this direction were obtained in [70], [46], [83].

3.2. Inverse problems for heterogeneous systems

The area of inverse problems covers a large class of theoretical and practical issues which are important in many applications (see for instance the books of Isakov [71] or Kaltenbacher, Neubauer, and Scherzer [73]). Roughly speaking, an inverse problem is a problem where one attempts to recover an unknown property of a given system from its response to an external probing signal. For systems described by evolution PDE, one can be interested in the reconstruction from partial measurements of the state (initial, final or current), the inputs (a source term, for instance) or the parameters of the model (a physical coefficient for example). For stationary or periodic problems (i.e. problems where the time dependence is given), one can be interested in determining from boundary data a local heterogeneity (shape of an obstacle, value of a physical coefficient describing the medium, etc.). Such inverse problems are known to be generally ill-posed and their study leads to investigate the following questions:

- *Uniqueness.* The question here is to know whether the measurements uniquely determine the unknown quantity to be recovered. This theoretical issue is a preliminary step in the study of any inverse problem and can be a hard task.

- *Stability.* When uniqueness is ensured, the question of stability, which is closely related to sensitivity, deserves special attention. Stability estimates provide an upper bound for the parameter error given some uncertainty on data. This issue is closely related to the so-called observability inequality in systems theory.
- *Reconstruction.* Inverse problems being usually ill-posed, one needs to develop specific reconstruction algorithms which are robust to noise, disturbances and discretization. A wide class of methods is based on optimization techniques.

We can split our research in inverse problems into two classes which both appear in FSIS and CWS:

1. **Identification for evolution PDE.**

   Driven by applications, the identification problem for systems of infinite dimension described by evolution PDE has seen in the last three decades a fast and significant growth. The unknown to be recovered can be the (initial/final) state (e.g. state estimation problems [39], [63], [67], [91] for the design of feedback controllers), an input (for instance source inverse problems [36], [48], [57]) or a parameter of the system. These problems are generally ill-posed and many regularization approaches have been developed. Among the different methods used for identification, let us mention optimization techniques ([50]), specific one-dimensional techniques (like in [40]) or observer-based methods as in [77].

   In the last few years, we have developed observers to solve initial data inverse problems for a class of linear systems of infinite dimension. Let us recall that observers, or Luenberger observers [76], have been introduced in automatic control theory to estimate the state of a dynamical system of finite dimension from the knowledge of an output (for more references, see for instance [80] or [93]). Using observers, we have proposed in [82], [68] an iterative algorithm to reconstruct initial data from partial measurements for some evolution equations.We are deepening our activities in this direction by considering more general operators or more general sources and the reconstruction of coefficients for the wave equation. In connection with this problem, we study the stability in the determination of these coefficients. To achieve this, we use geometrical optics, which is a classical albeit powerful tool to obtain quantitative stability estimates on some inverse problems with a geometrical background, see for instance [42], [41].

2. **Geometric inverse problems.**

   We investigate some geometric inverse problems that appear naturally in many applications, like medical imaging and non destructive testing. A typical problem we have in mind is the following: given a domain Ω containing an (unknown) local heterogeneity ω, we consider the boundary value problem of the form

$$\begin{cases} Lu = 0, & (\Omega \setminus \omega) \\ u = f, & (\partial\Omega) \\ Bu = 0, & (\partial\omega) \end{cases}$$

   where L is a given partial differential operator describing the physical phenomenon under consideration (typically a second order differential operator), B the (possibly unknown) operator describing the boundary condition on the boundary of the heterogeneity and f the exterior source used to probe the medium. The question is then to recover the shape of ω and/or the boundary operator B from some measurement Mu on the outer boundary $\partial\Omega$. This setting includes in particular inverse scattering problems in acoustics and electromagnetics (in this case Ω is the whole space and the data are far field measurements) and the inverse problem of detecting solids moving in a fluid. It also includes, with slight modifications, more general situations of incomplete data (i.e. measurements on part of the outer boundary) or penetrable inhomogeneities. Our approach to tackle this type of problems is based on the derivation of a series expansion of the input-to-output map of the problem (typically the Dirichlet-to-Neumann map of the problem for the Calderón problem) in terms of the size of the obstacle.

3.3. Numerical analysis and simulation of heterogeneous systems

Within the team, we have developed in the last few years numerical codes for the simulation of FSIS and CWS. We plan to continue our efforts in this direction.

- In the case of FSIS, our main objective is to provide computational tools for the scientific community, essentially to solve academic problems.
- In the case of CWS, our main objective is to build tools general enough to handle industrial problems. Our strong collaboration with Christophe Geuzaine's team in Liège (Belgium) makes this objective credible, through the combination of DDM (Domain Decomposition Methods) and parallel computing.

Below, we explain in detail the corresponding scientific program.

- **Simulation of FSIS:** In order to simulate fluid-structure systems, one has to deal with the fact that the fluid domain is moving and that the two systems for the fluid and for the structure are strongly coupled. To overcome this free boundary problem, three main families of methods are usually applied to numerically compute in an efficient way the solutions of the fluid-structure interaction systems. The first method consists in suitably displacing the mesh of the fluid domain in order to follow the displacement and the deformation of the structure. A classical method based on this idea is the A.L.E. (Arbitrary Lagrangian Eulerian) method: with such a procedure, it is possible to keep a good precision at the interface between the fluid and the structure. However, such methods are difficult to apply for large displacements (typically the motion of rigid bodies). The second family of methods consists in using a *fixed mesh* for both the fluid and the structure and to simultaneously compute the velocity field of the fluid with the displacement velocity of the structure. The presence of the structure is taken into account through the numerical scheme. Finally, the third class of methods consists in transforming the set of PDEs governing the flow into a system of integral equations set on the boundary of the immersed structure. The members of SPHINX have already worked on these three families of numerical methods for FSIS systems with rigid bodies (see e.g. [86], [74], [88], [84], [85], [78]).
- **Simulation of CWS:** Solving acoustic or electromagnetic scattering problems can become a tremendously hard task in some specific situations. In the high frequency regime (i.e. for small wavelength), acoustic (Helmholtz's equation) or electromagnetic (Maxwell's equations) scattering problems are known to be difficult to solve while being crucial for industrial applications (e.g. in aeronautics and aerospace engineering). Our particularity is to develop new numerical methods based on the hybridization of standard numerical techniques (like algebraic preconditioners, etc.) with approaches borrowed from asymptotic microlocal analysis. Most particularly, we contribute to building hybrid algebraic/analytical preconditioners and quasi-optimal Domain Decomposition Methods (DDM) [43], [58], [59] for highly indefinite linear systems. Corresponding three-dimensional solvers (like for example GetDDM) will be developed and tested on realistic configurations (e.g. submarines, complete or parts of an aircraft, etc.) provided by industrial partners (Thales, Airbus). Another situation where scattering problems can be hard to solve is the one of dense multiple (acoustic, electromagnetic or elastic) scattering media. Computing waves in such media requires us to take into account not only the interactions between the incident wave and the scatterers, but also the effects of the interactions between the scatterers themselves. When the number of scatterers is very large (and possibly at high frequency [38], [37]), specific deterministic or stochastic numerical methods and algorithms are needed. We introduce new optimized numerical methods for solving such complex configurations. Many applications are related to this problem *e.g.* for osteoporosis diagnosis where quantitative ultrasound is a recent and promising technique to detect a risk of fracture. Therefore, numerical simulation of wave propagation in multiple scattering elastic media in the high frequency regime is a very useful tool for this purpose.

4. Highlights of the Year

4.1. Highlights of the Year

4.1.1. Recruitments

Ludovick Gagnon has been recruited as a junior researcher (Chargé de recherche) in the team (from September 2018).

5. New Software and Platforms

5.1. GetDDM

KEYWORDS: Large scale - 3D - Domain decomposition - Numerical solver
FUNCTIONAL DESCRIPTION: GetDDM combines GetDP and Gmsh to solve large scale finite element problems using optimized Schwarz domain decomposition methods.

- Contact: Xavier Antoine
- URL: http://onelab.info/wiki/GetDDM

5.2. GPELab

Gross-Pitaevskii equations Matlab toolbox
KEYWORDS: 3D - Quantum chemistry - 2D
FUNCTIONAL DESCRIPTION: GPELab is a Matlab toolbox developed to help physicists for computing ground states or dynamics of quantum systems modeled by Gross-Pitaevskii equations. This toolbox allows the user to define a large range of physical problems (1d-2d-3d equations, general nonlinearities, rotation term, multi-components problems...) and proposes numerical methods that are robust and efficient.

- Contact: Xavier Antoine
- URL: http://gpelab.math.cnrs.fr/

6. New Results

6.1. Inverse problems for heterogeneous systems

Participants: David Dos Santos Ferreira, Karim Ramdani, Julie Valein, Alexandre Munnier, Jean-Claude Vivalda.

- In [32], we deal with a problem of observability for waves propagating in two environments with different speeds of propagation. We give an explicit construction of the regions of observability in the two-dimensional case. This allows us to determine in which locations we have to make some measurements in order to obtain the solution within the domain.
- In [33], we deal with the observability of the 1-D wave equation. The semi discretization of the waves problem leads to some uniform observability problems. This is due to the bad approximation of the high frequencies of discrete solutions. Some remedies are known, which involve finite element methods. In this paper, we give three methods allowing to retrieve the uniform observability when the approximations are made with a Galerkin method.
- In [15], Ramdani *et al.* proposed an algorithm for estimating from partial measurements the population for a linear age-structured population diffusion model. In this work, the physical parameters of the model were assumed to be known. The authors investigate the inverse problem of simultaneously estimating the population and the spatial diffusion coefficient for an age-structured population model. The measurement used is the time evolution of the population on a subdomain in space and age. The proposed method is based on the generalization to the infinite dimensional setting of an adaptive observer originally proposed for finite dimensional systems.

- In [13], Munnier and Ramdani proposed an explicit reconstruction formula for a two-dimensional cavity inverse problem. The proposed method was limited to the case of a single cavity due to the use of conformal mappings. In [13], Munnier and Ramdani consider the case of a finite number of cavities and aim to recover the location and the shape of the cavities from the knowledge of the Dirichlet-to-Neumann (DtN) map of the problem. The proposed reconstruction method is non iterative and uses two main ingredients. First, the authors show how to compute so-called generalized Pólia-Szegö tensors (GPST) of the cavities from the DtN of the cavities. Secondly, the authors shows that the obtained shape from GPST inverse problem can be transformed into a shape from moments problem, for some particular configurations. However, numerical results suggest that the reconstruction method is efficient for arbitrary geometries.
- In [2], we show that, generically, a (finite dimensional) sampled system is observable provided that the number of outputs is at least equal to the number of inputs plus 2. This work complements some previous works on the subject.
- In [18], we design a state observer for a coupled two dimensional partial differential equations (PDEs) system used to describe the heat transfer in a membrane distillation system for water desalination.

  In [23], we deal with uniqueness and stability issues for the inverse spectral problem of recovering the magnetic field and the electric potential in a Riemannian manifold from some asymptotic knowledge of the boundary spectral data of the corresponding Schrödinger operator under Dirichlet boundary conditions.

6.2. Control and stabilization of heterogeneous systems

Participants: Thomas Chambrion, David Dos Santos Ferreira, Takéo Takahashi, Julie Valein.

- In [8], we find, thanks to a a semiclassical approach, L^p estimates for the resolvants of the damped wave operator given on compact manifolds whose dimension is greater than 2.
- In [27], we have proved a “Ball-Marsedn-Slemrod” obstruction to the bi-linear controllability of the Klein-Gordon equation. With different methods, we obtained comparable results for the Gross-Pitaevskii equation in [28].
- In [7], we study the local exponential stability of the nonlinear Korteweg-de Vries equation with boundary time-delay feedback by using two different methods: a Lyapunov functional approach (with an estimation on the decay rate, but with a restrictive assumption on the length of the spatial domain) and an observability inequality approach (for any non critical lengths).
- In [12], we study the local controllability to trajectories of a Burgers equation with nonlocal viscosity. By linearization we are led to an equation with a non local term whose controllability properties are analyzed by using Fourier decomposition and biorthogonal techniques. Once the existence of controls is proved and the dependence of their norms with respect to the time is established for the linearized model, a fixed point method allows us to deduce the result for the nonlinear initial problem.
- In [26], we establish a Lebeau-Robbiano spectral inequality for a degenerated one dimensional elliptic operator and show how it can be used to impulse control and finite time stabilization for a degenerated parabolic equation.
- In [25], We prove a Carleman estimate in a neighborhood of a multi-interface, under compatibility assumptions between the Carleman weight, the operators at the multi-interface, and the elliptic operators in the interior and the usual sub-ellipticity condition. We derive some properties of unique prolongation, control of the heat equation, and satblization of the related damped waves equation.

6.3. Numerical analysis and simulation of heterogeneous systems

Participant: Xavier Antoine.

- In [10], we design some accurate artificial boundary conditions for the semi-discretized linear Schrödinger and heat equations in rectangular domains. We show the accuracy of the method thanks to simulations
- In [5], we design fast numerical and highly accurate methods for the computation of steady states and the dynamics of time or space-fractional Schrödinger equations.
- In [1], we design a numerical model of diffusion for the study of the properties of noble gases originating from volcanic eruptions.
- In [4], the deal with a multilevel Schwarz Waveform Relaxation (SWR) Domain Decomposition Method (DDM) for the Non Linear Schrödinger Equation (NLSE).
- In [6], we design a fast and pseudo spectral preconditioned conjugated gradient method for the computation of the steady states related to the Gross-Pitaevskii equation with non local dipolar interaction.
- In [3], we deal with fractional microlocal analysis for the obtention of asymptotic estimates for the convergence of Schwarz Waveform Relaxation (SWR) domain decomposition method; this study is done is the two dimensional quantum case.
- In [11], we design new methods of very high order for the computation of diffracted fields; these methods rely on a B-splines finite element method and are related to the isogeometric analysis.
- In [17], we deal with the numerical analysis of fast and accurate schemes for solving one-dimensional time-fractional nonlinear Schrödinger equations set with artificial boundaries.
- In [35], we obtain a close approximation of the optimal parameters for the convergence of domain decomposition methods for the Schrödinger equation.
- In [19], we compute an explicit approximation of the optimal parameters for the convergence of domain decomposition methods for the Schrödinger equation.
- In [21], we introduce an original method in order to integrate PML in a pseudospectral method for the computation of the dynamics of the Dirac equation. Some applications to lasers are given.
- In [20], we deal with the asymptotic analysis of the rate of convergence of the classical and quasi-optimal Schwarz waveform relaxation (SWR) method for solving the linear Schrödinger equation.

6.4. Fluid-Structure Interaction

Participants: Julien Lequeurre, Jean-François Scheid.

In [16], we deal with shape optimization problem for a Stokes/elasticity system. The aim is to find the optimal shape of an elastic structure which minimizes an energy type functional. Results are obtained for a simplified free-boundary one-dimensional problem.

In [34], we design a hilbertian framework for the analysis of the planar Navier-Stokes (NS) equations either in vorticity or in stream function formulation. The fluid is assumed to occupy a bounded possibly multiply connected domain. The velocity field satisfies either homogeneous (no-slip boundary conditions) or prescribed Dirichlet boundary conditions. We prove that the proposed approach is equivalent to the classical one (stated in primitive variables, i.e. velocity and pressure fields) for strong and weak solutions. In particular . In particular, in both cases, we retrieve the pressure from the vorticity or the current function.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Grants with Industry

From April 2018, Th. Chambrion is the advisor of a thesis, which is funded by Saint Gobain Research (CIFRE contract). The aim of this thesis is to improve the cast process used in the Saint Gobain pipes factory of Pont-à -Mousson. Complex physical processes (centrifugation of multi-phasic flows with variable viscosity) prevent a physical based modeling approach. Using a statistical modeling of the plant, we aim to obtain efficient control laws and a significative cost reduction.

8. Partnerships and Cooperations

8.1. Regional Initiatives

8.1.1. Lorraine Université d'Excellence

Thomas Chambrion is deputy head of working group 2 of the Deepsurf project (a project of LUE). ...

8.2. National Initiatives

8.2.1. ANR

- **Project Acronym :** IFSMACS
  Project Title : Fluid-Structure Interaction: Modeling, Analysis, Control and Simulation
  Coordinator: Takéo Takahashi
  Participants: Julien Lequeurre, Alexandre Munnier, Jean-François Scheid, Takéo Takahashi
  Duration : 48 months (starting on October 1st, 2016)
  Other partners: Institut de Mathématiques de Bordeaux, Inria Paris, Institut de Mathématiques de Toulouse
  Abstract: The aim of this project is to analyze systems composed by structures immersed in a fluid. Studies of such systems can be motivated by many applications (motion of the blood in veins, fish locomotion, design of submarines, etc.) but also by the corresponding challenging mathematical problems. Among the important difficulties inherent to these systems, one can quote nonlinearity, coupling, free-boundaries. Our objectives include asymptotic analyses of FSIS, the study of controllability and stabilizability of FSIS, the understanding of locomotion of self-propelled structures and the analyze and development of numerical tools to simulate fluid-structure system.
  URL: http://ifsmacs.iecl.univ-lorraine.fr/
- **Project Acronym:** QUACO
  Project title: use of geometrical tools for the control of quantum system and application to MRI.
  Coordinator: Thomas Chambrion
  Duration: 48 months (starting January 1st 2018).
  URL: http://www.iecl.univ-lorraine.fr/~Thomas.Chambrion/QUACO/index.html
- **Project acronym:** ISDEEC
  Project title: Interaction entre Systèmes Dynamiques, Equations d'Evolution et Contrôle
  Coordinator: Romain Joly
  Participant: Julie Valein
  Other partners: Institut Fourier, Grenoble; Département de Mathématiques d'Orsay
  Duration: 36 months (2017-2020)
  URL: http://isdeec.math.cnrs.fr/

8.2.2. CNRS

Thomas Chambrion is the coordinator of the Research Project from CNRS Inphynity "DISQUO" (5300 euros, 2017).

8.3. International Initiatives

8.3.1. Participation in International Programs

8.3.1.1. Indo-French Center of Applied Mathematics

Analysis, Control and Homogenization of Complex Systems

International Partner: TIFR CAM, Bangalore

Heads: Takéo Takahashi (France) and Mythily Ramaswamy (India).

Duration: 2018 - 2021

scientific objectives

- Study the well-posedness of models arising from either structure in the fluid or structure on the boundary of the domain containing the fluid.
- Explore Controllability, Optimal Control and Stabilization of such fluid-structure interaction problems.
- Study systems describing fluid flows in a time dependent domain with a rapidly oscillating boundary using Homogenization Theory. The rapid oscillations of the boundary takes into account, the rough character of the boundary and its movements may take into account the displacement of a deformable body into a fluid flow.
- Carry out Finite Element Analysis for such models, including elastic structures as well as rigid ones.

8.4. International Research Visitors

8.4.1. Visits to International Teams

8.4.1.1. Research Stays Abroad

- Xavier Antoine was invited
  - to Beijing CSRC, Beijing + Department of Mechanics and Engineering Science, Beijing, July 2018 (one week);
  - to the Department of Mathematics, Sichuan University, Chengdu, Augutst 2018 (3.5 weeks);
  - to the Department of Mathematics, Sichuan University, Chengdu, January 2019 (2 weeks).
- Julie Valein staid for 10 days in Valparaiso (Chile) and gave a talk to the workshop ICoPS 2018; she staid in Santiago (2-14 December 2018) to collaborate with E. Cerpa.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. General Chair, Scientific Chair

"rQUACO" is the first meeting funded by the ANR QUACO. This 3 days workshop of quantum control gathers 25 physicists and mathematicians in September in Besançon and was co-organized by N. Boussaïd (UBFC Besançon), T. Chambrion (U. Lorraine) and S. Sugny (UBFC Dijon).

9.1.1.2. Member of the Organizing Committees

- Xavier Antoine was a member of the scientific committee of ECT2018, The 10$^{\text{th}}$ International Conference on Engineering Computational Technology, Barcelona, Spain, 4–6 September 2018. He was also a co-organiser of the workshop on Mathematical and Computational Methods for Quantum Systems, CRM Montréal, 11-14th December 2018.
- Thomas Chambrion was a member of the organizing committee of rQUACO, which took place under the framework of the ANR QUACO;
- David Dos Santos Ferreira was a co-organizer (with Laurent Thomann) of the ”*Journées EDP*” (Obernai, June 2018);
- Julien Lequeurre and Alexandre Munnier were co-organizers of the JEF “Journées Jeunes Edpistes” (Mars 2018, Nancy https://jef18.sciencesconf.org).
- Julie Valein was a member of the organizing committee of the meeting “Contrôle et dynamique des EDP", which took place under the framework of the ANR ISDEEC, (28–30 March 2018, http://isdeec.math.cnrs.fr/rencontres.html).

9.1.2. Journal

9.1.2.1. Member of the Editorial Boards

- Xavier Antoine is associate editor of “Multiscale in Science and Engineering” (Springer) and “International Journal of Computer Mathematics” (Taylor and Francis);
- David Dos Santos Ferreira is member of the editorial board of “Mathematical Control and Related Fields”;
- Jean-Claude Vivalda is a member of the editorial board of the “Journal of Dynamical and Control Systems”.

9.1.2.2. Reviewer - Reviewing Activities

- Jean-François Scheid is reviewer for the “Applied Mathematics and Optimization” journal;
- Jean-Claude Vivalda is reviewer for the “Mathematical reviews”.

9.1.3. Invited Talks

- Xavier Antoine was invited to give a talk to
  - the mini-symposium ”Waves and computation”, Hong-Kong, 4-7 June, 2018;
  - the workshop ”Méthodes numériques multi-échelles et/ou géométriques pour les équations de types cinétique ou Schrödinger,”, Rennes, 12-15 June 2018;
  - the workshop ”Modern Numerical Methods in Quantum Mechanics”, 27-29 June 2018, Gdansk, Poland;
  - ”Forum on Applied and Computational Mathematics”, July 22-23, 2018, Beijing CSRC.
- Alexandre Munnier was invited to give a talk at the “Groupe de travail EDP of the IECL”;
- Julie Valein was invited to give a talk at
  - the 14th Franco-Romanian conference on applied mathematics, (Bordeaux, Auguts 27–31 2018);
  - the conference “Analysis of PDEs : unique continuation, stabilization, control and dispersive properties”, in honour of Pr. L. Robbiano – IHP, Paris, November 5–9 2018 (one hour plenary exposition);
  - 2nd DECOD Workshop (DElays and COnstraints in Distributed parameter systems) – Toulouse, November 21–23 2018 (45 minutes plenary exposition).
- Jean-Claude Vivalda was invited to give a talk at the “Séminaires et journées d’Equations aux Dérivées Partielles“ in the maths laboratory of Versailles.

9.1.4. Leadership within the Scientific Community

- Xavier Antoine is the director of the maths laboratory IECL.
- David Dos Santos Ferreira is one of the coordinators of the GDR “Analyse des EDP”. He is also the treasurer of the SMF (French mathematical society);
- Julien Lequeurre is responsable of the “Séminaire EDP de l’Institut Elie Cartan de Lorraine, site de Metz”
- Julie Valein is co-responsable of the “Séminaire EDP de l’Institut Elie Cartan de Lorraine, site de Nancy”.

9.1.5. Scientific Expertise

Julie Valein participated in a associate professor position recruitment committee at Université de La Rochelle and at Université de Bordeaux (April-May 2018).

9.1.6. Research Administration

- Karim Ramdani is member of the board of the RNBM (Réseau National des Bibliothèques de Mathématiques) and is in charge of Open Access issues (with Benoît Kloeckner). Since October 2018, he is also member of the Working Group “Publications” of the national “Comité pour la Science Ouverte” of the french ministry of Higher Education, Research and Innivation.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Except L. Gagnon, K. Ramdadi, T. Takahashi and J.-C. Vivalda, SPHINX members have teaching obligations at "Université de Lorraine" and are teaching at least 192 hours each year. They teach mathematics at different level (Licence, Master, Engineering school). Many of them have pedagogical responsibilities.

9.2.2. Supervision

PhD defended :

- Boris Caudron, June 2018, (Thèse CIFRE Thalès) , supervisor: X. Antoine.
- Benjamín Obando defended his PhD thesis “Mathematical models for the study of granular fluids” at Santiago on 18th December 2018. Supervisors: Jorge San Martín (University of Chile) and Takéo Takahashi.

PhD in progress:

- Mohamed ID SAID, Embedded automatic control with limited computational resources, from October 2017, supervisors: T. Chambrion and G. Millerioux;
- PhD in progress: Meriem BOUGUEZZI, Reaction-diffusion system for the modeling of a corrosion phenomena, from november 2017, J.-F. Scheid (co-supervisor);
- PhD in progress: Imem JBIL, Myocardial infarction as a fluid-structure system : modeling and simulations, from mars 2017, J.-F. Scheid (co-supervisor);
- PhD in progress: Imene DJEBOUR, Control and inverse problems on fluid-structure interaction systems, from November 2017, supervisor : T. Takahashi.

9.2.3. Juries

- David Dos Santos Ferreira Jury was a member of the thesis jury of Matthieu Léautaud and Cristó bal Meroño.
- Takéo Takahashi reviewed the PhD theses of
  - Krisztián Benyó (defense on 25/09/2018 at Bordeaux);
  - Thi Minh Nhat Vo (defense on 04/10/2018 at Orléans);

   - Lamis Sabbagh (defense on 22/11/2018 at Montpellier).
- Julie Valein was a member of the thesis jury of Hawraa Nabolsi, defended in July 2018, at "Université de Valenciennes et du Hainaut-Cambrésis" (Title: "Contrôle optimal des équations d'évolution et ses applications.", Advisors : Luc Paquet and Ali Wehbe.)
- Xavier Antoine served as a referee for the PhD thesis of Huda Al Taie, (Dec. 2018, Université de Nice).

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