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Project-Team DEFI

Shape reconstruction and identification

IN COLLABORATION WITH: Centre de Mathématiques Appliquées (CMAP)

RESEARCH CENTER
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THEME
Computational models and simulation

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Project-Team DEFI

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2. Overall Objectives

2.1. Overall Objectives

The research activity of our team is dedicated to the design, analysis and implementation of efficient numerical methods to solve inverse and shape/topological optimization problems in connection with acoustics, electromagnetism, elastodynamics, and diffusion.

Sought practical applications include radar and sonar applications, bio-medical imaging techniques, non-destructive testing, structural design, composite materials, and diffusion magnetic resonance imaging.

Roughly speaking, the model problem consists in determining information on, or optimizing the geometry (topology) and the physical properties of unknown targets from given constraints or measurements, for instance, measurements of diffracted waves or induced magnetic fields.

In general this kind of problems is non linear. The inverse ones are also severely ill-posed and therefore require special attention from regularization point of view, and non-trivial adaptations of classical optimization methods.

Our scientific research interests are the following:

- Theoretical understanding and analysis of the forward and inverse mathematical models, including in particular the development of simplified models for adequate asymptotic configurations.
- The design of efficient numerical optimization/inversion methods which are quick and robust with respect to noise. Special attention will be paid to algorithms capable of treating large scale problems (e.g. 3-D problems) and/or suited for real-time imaging.
- Development of prototype softwares for specific applications or tutorial toolboxes.

2.2. Highlights

- In 2011 Grégoire Allaire received the Grand Prix de la Fondation d'entreprise EADS (sciences and engineering) awarded by the Académie des Sciences de Paris.

3. Scientific Foundations

3.1. Scientific Foundations

The research activity of our team is dedicated to the design, analysis and implementation of efficient numerical methods to solve inverse and shape/topological optimization problems in connection with wave imaging, structural design, non-destructive testing and medical imaging modalities. We are particularly interested in the development of fast methods that are suited for real-time applications and/or large scale problems. These goals require to work on both the physical and the mathematical models involved and indeed a solid expertise in related numerical algorithms.

This section intends to give a general overview of our research interests and themes. We choose to present them through the specific academic example of inverse scattering problems (from inhomogeneities), which is representative of foreseen developments on both inversion and (tological) optimization methods. The practical problem would be to identify an inclusion from measurements of diffracted waves that result from the interaction of the sought inclusion with some (incident) waves sent into the probed medium. Typical applications include biomedical imaging where using micro-waves one would like to probe the presence of pathological cells, or imaging of urban infrastructures where using ground penetrating radars (GPR) one is interested in finding the location of buried facilities such as pipelines or waste deposits. This kind of applications requires in particular fast and reliable algorithms.

By "imaging" we shall refer to the inverse problem where the concern is only the location and the shape of the inclusion, while "identification" may also indicate getting informations on the inclusion physical parameters.

Both problems (imaging and identification) are non linear and ill-posed (lack of stability with respect to measurements errors if some careful constrains are not added). Moreover, the unique determination of the geometry or the coefficients is not guaranteed in general if sufficient measurements are not available. As an example, in the case of anisotropic inclusions, one can show that an appropriate set of data uniquely determine the geometry but not the material properties.

These theoretical considerations (uniqueness, stability) are not only important in understanding the mathematical properties of the inverse problem, but also guide the choice of appropriate numerical strategies (which information can be stably reconstructed) and also the design of appropriate regularization techniques. Moreover, uniqueness proofs are in general constructive proofs, i.e. they implicitly contain a numerical algorithm to solve the inverse problem, hence their importance for practical applications. The sampling methods introduced below are one example of such algorithms.

A large part of our research activity is dedicated to numerical methods applied to the first type of inverse problems, where only the geometrical information is sought. In its general setting the inverse problem is very challenging and no method can provide a universal satisfactory solution to it (regarding the balance cost-precision-stability). This is why in the majority of the practically employed algorithms, some simplification of the underlying mathematical model is used, according to the specific configuration of the imaging experiment. The most popular ones are geometric optics (the Kirchhoff approximation) for high frequencies and weak scattering (the Born approximation) for small contrasts or small obstacles. They actually give full satisfaction for a wide range of applications as attested by the large success of existing imaging devices (radar, sonar, echography, X-ray tomography, ...), that rely on one of these approximations.

Generally speaking, the used simplifications result into a linearization of the inverse problem and therefore are usually valid only if the latter is weakly non-linear. The development of these simplified models and the improvement of their efficiency is still a very active research area. With that perspective we are particularly interested in deriving and studying higher order asymptotic models associated with small geometrical parameters such as: small obstacles, thin coatings, wires, periodic media, ... Higher order models usually introduce some non linearity in the inverse problem, but are in principle easier to handle from the numerical point of view than in the case of the exact model.

A larger part of our research activity is dedicated to algorithms that avoid the use of such approximations and that are efficient where classical approaches fail: i.e. roughly speaking when the non linearity of the inverse problem is sufficiently strong. This type of configuration is motivated by the applications mentioned below, and occurs as soon as the geometry of the unknown media generates non negligible multiple scattering effects (multiply-connected and closely spaces obstacles) or when the used frequency is in the so-called resonant region (wave-length comparable to the size of the sought medium). It is therefore much more difficult to deal with and requires new approaches. Our ideas to tackle this problem will be motivated and inspired by recent advances in shape and topological optimization methods and also the introduction of novel classes of imaging algorithms, so-called sampling methods.

The sampling methods are fast imaging solvers adapted to muli-static data (multiple receiver-transmitter pairs) at a fixed frequency. Even if they do not use any linearization the forward model, they rely on computing the solutions to a set of linear problems of small size, that can be performed in a completely parallel procedure. Our team has already a solid expertise in these methods applied to electromagnetic 3-D problems. The success of such approaches was their ability to provide a relatively quick algorithm for solving 3-D problems without any need for a priori knowledge on the physical parameters of the targets. These algorithms solve only the imaging problem, in the sense that only the geometrical information is provided.

Despite the large efforts already spent in the development of this type of methods, either from the algorithmic point of view or the theoretical one, numerous questions are still open. These attractive new algorithms also suffer from the lack of experimental validations, due to their relatively recent introduction. We also would like to invest on this side by developing collaborations with engineering research groups that have experimental facilities. From the practical point of view, the most potential limitation of sampling methods would be the need of a large amount of data to achieve a reasonable accuracy. On the other hand, optimization methods do not suffer from this constrain but they require good initial guess to ensure convergence and reduce the number of iterations. Therefore it seems natural to try to combine the two class of methods in order to calibrate the balance between cost and precision.

Among various shape optimization methods, the Level Set method seems to be particularly suited for such a coupling. First, because it shares similar mechanism as sampling methods: the geometry is captured as a level set of an “indicator function” computed on a caretisian grid. Second, because the two methods do not require any a priori knowledge on the topology of the sought geometry. Beyond the choice of a particular method, the main question would be to define in which way the coupling can be achieved. Obvious strategies consist in using one method to pre-process (initialization) or post-process (find the level set) the other. But one can also think of more elaborate ones, where for instance a sampling method can be used to optimize the choice of the incident wave at each iteration step.The latter point is closely related to the design of so clalled “focusing incident waves” (which are for instance the basis of applications of the time-reversal principle). In the frequency regime, these incident waves can be constructed from the eigenvalue decomposition of the data operator used by sampling methods. The theoretical and numerical investigations of these aspects are still not completely understood for electromagnetic or elastodynamic problems.

Other topological optimization methods, like the homogenization method or the topological gradient method, can also be used, each one provides particular advantages in specific configurations. It is evident that the development of these methods is very suited to inverse problems and provide substantial advantage compared to classical shape optimization methods based on boundary variation. Their applications to inverse problems has not been fully investigated. The efficiency of these optimization methods can also be increased for adequate asymptotic configurations. For instance small amplitude homogenization method can be used as an efficient relaxation method for the inverse problem in the presence of small contrasts. On the other hand, the topological gradient method has shown to perform well in localizing small inclusions with only one iteration.

For the identification problem, one would like to also have information of the physical properties of the targets. Of course optimization methods is a tool of choice for these problems. However, in some applications only a qualitative information is needed and obtaining it in a cheaper way can be performed using asymptotic theories combined with sampling methods.

A broader perspective of our research themes would be the extension of the above mentioned techniques to time-dependent cases. Taking into account data in time domain is important for many practical applications, such as imaging in cluttered media, the design of absorbing coatings or also crash worthiness in the case of structural design.

We are also interested in diffusion type problems in the field of medical imaging. Diffusion MRI (DMRI) gives a measure of the average distance travelled by water molecules in a certain medium and can give useful information on cellular structure and structural change when the medium is biological tissue. In particular, we would like to infer from DMRI measurements changes in the cellular volume fraction occurring upon various physiological or pathological conditions as well as the average cell size in the case of tumor imaging.

We model the magnetization in biological tissue due to a diffusion magnetic field gradient at the voxel level by a multiple compartment Bloch-Torrey partial differential equation, which is a diffusive-type time-dependent PDE. The DMRI signal is the integral of the solution of the Bloch-Torrey PDE. In a homogeneous medium, the intrinsic diffusion coeffcient D will appear as the slope of the semi-log plot of the signal (in approporiate units). However, because during typical scanning times, $50-100ms$, water molecules have had time to travel a diffusion distance which is long compared to the average size of the cells, the slope of the semi-log plot of the signal is in fact a measure of an 'effective' diffusion coefficient. In DMRI applications, this measured quantity is called the 'apparent diffusion coefficient' (ADC). This ADC is closely related to the effective diffusion coefficient obtainable from mathematical homogenization theory.

4. Application Domains

4.1. Radar and GPR applications

Conventional radar imaging techniques (ISAR, GPR, ...) use backscattering data to image targets. The commonly used inversion algorithms are mainly based on the use of weak scattering approximations such as the Born or Kirchhoff approximation leading to very simple linear models, but at the expense of ignoring multiple scattering and polarization effects. The success of such an approach is evident in the wide use of synthetic aperture radar techniques.

However, the use of backscattering data makes 3-D imaging a very challenging problem (it is not even well understood theoretically) and as pointed out by Brett Borden in the context of airborne radar: “In recent years it has become quite apparent that the problems associated with radar target identification efforts will not vanish with the development of more sensitive radar receivers or increased signal-to-noise levels. In addition it has (slowly) been realized that greater amounts of data - or even additional “kinds” of radar data, such as added polarization or greatly extended bandwidth - will all suffer from the same basic limitations affiliated with incorrect model assumptions. Moreover, in the face of these problems it is important to ask how (and if) the complications associated with radar based automatic target recognition can be surmounted." This comment also applies to the more complex GPR problem.

Our research themes will incorporate the development, analysis and testing of several novel methods, such as sampling methods, level set methods or topological gradient methods, for ground penetrating radar application (imaging of urban infrastructures, landmines detection, underground waste deposits monitoring, ...) using multistatic data.

4.2. Biomedical imaging

Among emerging medical imaging techniques we are particularly interested in those using low to moderate frequency regimes. These include Microwave Tomography, Electrical Impedance Tomography and also the closely related Optical Tomography technique. They all have the advantage of being potentially safe and relatively cheap modalities and can also be used in complementarity with well established techniques such as X-ray computed tomography or Magnetic Resonance Imaging.

With these modalities tissues are differentiated and, consequentially can be imaged, based on differences in dielectric properties (some recent studies have proved that dielectric properties of biological tissues can be a strong indicator of the tissues functional and pathological conditions, for instance, tissue blood content, ischemia, infarction, hypoxia, malignancies, edema and others). The main challenge for these functionalities is to built a 3-D imaging algorithm capable of treating multi-static measurements to provide real-time images with highest (reasonably) expected resolutions and in a sufficiently robust way.

Another important biomedical application is brain imaging. We are for instance interested in the use of EEG and MEG techniques as complementary tools to MRI. They are applied for instance to localize epileptic centers or active zones (functional imaging). Here the problem is different and consists into performing passive imaging: the epileptic centers act as electrical sources and imaging is performed from measurements of induced currents. Incorporating the structure of the skull is primordial in improving the resolution of the imaging procedure. Doing this in a reasonably quick manner is still an active research area, and the use of asymptotic models would offer a promising solution to fix this issue.

4.3. Non destructive testing and parameter identification

One challenging problem in this vast area is the identification and imaging of defaults in anisotropic media. For instance this problem is of great importance in aeronautic constructions due to the growing use of composite materials. It also arises in applications linked with the evaluation of wood quality, like locating knots in timber in order to optimize timber-cutting in sawmills, or evaluating wood integrity before cutting trees. The anisotropy of the propagative media renders the analysis of diffracted waves more complex since one cannot only relies on the use of backscattered waves. Another difficulty comes from the fact that the micro-structure of the media is generally not well known a priori.

Our concern will be focused on the determination of qualitative information on the size of defaults and their physical properties rather than a complete imaging which for anisotropic media is in general impossible. For instance, in the case of homogeneous background, one can link the size of the inclusion and the index of refraction to the first eigenvalue of so-called interior transmission problem. These eigenvalues can be determined form the measured data and a rough localization of the default. Our goal is to extend this kind of idea to the cases where both the propagative media and the inclusion are anisotropic. The generalization to the case of cracks or screens has also to be investigated.

In the context of nuclear waste management many studies are conducted on the possibility of storing waste in a deep geological clay layer. To assess the reliability of such a storage without leakage it is necessary to have a precise knowledge of the porous media parameters (porosity, tortuosity, permeability, etc.). The large range of space and time scales involved in this process requires a high degree of precision as well as tight bounds on the uncertainties. Many physical experiments are conducted *in situ* which are designed for providing data for parameters identification. For example, the determination of the damaged zone (caused by excavation) around the repository area is of paramount importance since microcracks yield drastic changes in the permeability. Level set methods are a tool of choice for characterizing this damaged zone.

4.4. Diffusion MRI

- Detecting physiological and pathological conditions that are accompanied by higher or lower than normal diffusion MRI signal attenuation. Examples: immediately after stroke, there is a large drop in the measured apparent diffusion coefficient; demyelinating diseases of the central nervous system have been indicated by higher than normal radial diffusivity.
- Evaluating cancer treatment by quantifying tumor cellularity based on diffusion MRI measurements. Tumor cellularity is shown to be inversely correlated to measured diffusivity.

5. Software

5.1. RODIN

Participant: Grégoire Allaire [correspondant].

One of the aims of the RODIN project is to develop a new shape optimization software for solid structures in the framework of the SYSTUS code developed by ESI-group. The work has just started.

5.2. FreeFem++ Toolboxes

5.2.1. Shape optimization toolbox in FreeFem++

Participants: Grégoire Allaire, Olivier Pantz.

We propose several FreeFem++ routines which allow the users to optimize the thickness, the geometry or the topology of elastic structures. All examples are programmed in two space dimensions. These routines have been written by G. Allaire, B. Boutin, C. Dousset, O. Pantz. A web page of this toolbox is available at http://www.cmap.polytechnique.fr/~allaire/freefem_en.html.

We also have written a C++ code to solve the Hamilton Jacoby equation used in the Level-set shape optimization method. This code has been linked with FreeFem++ routines.

5.2.2. Inverse Problems for Stokes Flows

Participants: Armin Lechleiter [correspondant], Tobias Rienmüller.

This software solves shape reconstruction inverse problems for the Stokes-Brinkmann equaions modelling porous penetrable inclusions inside a free flow. This problem is motivated by non-destructive testing in pipes and reservoirs. The factorization method is used to solve the inverse problem.

5.2.3. Inverse shape and medium problem for thin coatings

Participant: Nicolas Chaulet.

We developed a FreeFem++ toolbox which retrieve an obstacle and two coefficients that define a generalized impedance boundary condition form a few far field data in dimension 2. The reconstruction algorithm relies on regularized non linear optimization technique. The toolbox also contains a forward solver for the scattering of acoustic waves by obstacle on which a generalized impedance boundary condition is applied using an approximate Dirichlet-to-Neuman map to bound the computational domain.

5.2.4. Inverse shape problems for axisymmetric eddy current problems

Participants: Armin Lechleiter, Zixian Jiang [correspondant].

This FreeFem++ toolbox solves inverse problems for an axisymmetric eddy current model using shape optimization techniques. The underlying problem is to find inclusions in a tubular and unbounded domain. The direct scattering problems are solved using an adaptive finite element method, and Dirichlet-to-Neumann operators are used to implement the transparent boundary conditions. Based on the shape derivative of an inclusion with respect to the domain, the toolbox offers regularized iterative algorithms to solve the inverse problem.

5.2.5. Contact managements

Participant: Olivier Pantz.

We have developed a toolbox running under Freefem++ in order to take into account the non-intersection constraints between several deformable bodies. This code has been used to treat contacts between red blood cells in our simulations, but also between genuine non linear elastic structure. It can handle both contacts and self-contacts.
Moreover, a toolbox based on the Penalization method has also been developed.

5.2.6. De-Homogenization

Participant: Olivier Pantz.

We have developed a code under Freefem++ that implements our De-Homogenization method. It has been used to solve the compliance minimization problem of the compliance of an elastic shape. In particular, it enables us to recover well known optimal Michell's trusses for shapes of low density.

5.3. Scilab and Matlab Toolboxes

5.3.1. Shape optimization toolbox in Scilab

Participant: Grégoire Allaire [correspondant].

Together with Georgios Michailidis, we improved a Scilab toolbox for 2-d shape and topology optimization by the level set method which was originally produced by Anton Karrman and myself. The routines, a short user's manual and several examples are available on the web page.

5.3.2. Conformal mapping method

Participant: Houssem Haddar [correspondant].

This Scilab toolbox is dedicated to the resolution of inverse 2-D electrostatic problems using the conformal mapping method introduced by Akdumann, Kress and Haddar. The toolbox treats the cases of a simply connected obstacle with Dirichlet, Neumann or impedance boundary conditions or a simply connected inclusion with a constant conductivity.

5.3.3. Direct and inverse problems in waveguides

Participants: Armin Lechleiter [correspondant], Dinh Liem Nguyen.

This Matlab toolbox includes fast solvers for direct and inverse scattering problems in planar 3D waveguides for inhomogeneous media The direct scattering problems are solved using an spectral integral equation approach relying on the Lippmann-Schwinger integral equation, discretized as a Galerkin method via the fast Fourier transform. The toolbox includes preconditioning by a two-grid scheme and multipole expansions coupled to the spectral solver to allow for multiple scattering objects. The inverse problem to find the shape of the scattering object from near-field measurements is solved using a Factorization method.

5.4. Sampling methods for inverse problems

5.4.1. Samplings-2d

Participant: Houssem Haddar [correspondant].

This software is written in Fortran 90 and is related to forward and inverse problems for the Helmholtz equation in 2-D. It includes three independent components. The first one solves to scattering problem using integral equation approach and supports piecewise-constant dielectrics and obstacles with impedance boundary conditions. The second one contains various samplings methods to solve the inverse scattering problem (LSM, RGLSM(s), Factorization, MuSiC) for near-field or far-field setting. The third component is a set of post processing functionalities to visualize the results
See also the web page http://sourceforge.net/projects/samplings-2d/.

- License: GPL
- Type of human computer interaction: sourceforge
- OS/Middelware: Linux
- Programming language: Fortran
- Documentation: fichier

5.4.2. Samplings-3d

Participant: Houssem Haddar [correspondant].

This software is written in Fortran 90 and is related to forward and inverse problems for the Helmholtz equation in 3-D. It contains equivalent functionalities to samplings-2d in a 3-D setting.

5.4.3. Time domain samplings-2d

Participants: Houssem Haddar [correspondant], Armin Lechleiter.

This software is written in Fortran 90 and is related to forward and inverse problems for the time dependent wave equation in 2-D. The forward solver is based on a FDTD method with PMLs. The inverse part is an implementation of the linear sampling method in a near field setting and the factorization method in a far field setting.

5.4.4. Factorization Method for EIT

Participant: Giovanni Migliorati.

We developed a numerical code that implements the Factorization Method applied to the Continuous Model, in the framework of Electrical Impedance Tomography featuring an inhomogeneous background. The numerical scheme relies on the approximation by the finite element method of the solution to the dipole-like Neumann boundary-value problem. Two regularization techniques are implemented, i.e. the Tikhonov regularization embedding Morozov principle, and the classical Picard Criterion. The numerical analysis of the method and the results obtained are presented in the INRIA RR-7801, November 2011.

5.5. FVforBlochTorrey

Participant: Jing-Rebecca Li [correspondant].

Finite volume code in Fortran 90 to solve the multiple compartment Bloch Torrey equation in 2D and 3D to simulate the bulk magnetization of a sample under the influence of a diffusion gradient. We couple a mass-conserving finite volume discretization in space with a stable time discretization using an explicit Runge-Kutta-Chebyshev method and we are able to solve the Bloch-Torrey PDE in multiple compartments for an arbitrary diffusion sequence with reasonable accuracy for moderately complicated geometries in computational time that is on the order of tens of minutes per bvalue on a laptop computer.
See also the web page http://www.cmap.polytechnique.fr/~jingrebeccali/.

6. New Results

6.1. Sampling methods for inverse scattering problems

6.1.1. Sampling methods with time dependent data

Participants: Houssem Haddar, Armin Lechleiter, Simon Marmorat.

We considered the extension of the so-called Factorization method to far-field data in the time domain . For a Dirichlet scattering object and incident wave fronts, the inverse problem under investigation consists in characterizing the shape of the scattering object from the behaviour of the scattered field far from the obstacle (far-field measurements). We derive a self-adjoint factorization of the time-domain far-field operator and show that the middle operator of this factorization possesses a weak type of coercivity. This allows to prove range inclusions between the far-field operator and the time-domain Herglotz operator .

We also extended the near-field version of the linear sampling method to causal time-dependent wave data for smooth, band-limited incident pulses, considering different boundary conditions as for instance Dirichlet, Neumann or Robin conditions [27].

6.1.2. Inverse problems for periodic penetrable media

Participants: Armin Lechleiter, Dinh Liem Nguyen.

Imaging periodic penetrable scattering objects is of interest for non-destructive testing of photonic devices. The problem is motivated by the decreasing size of periodic structures in photonic devices, together with an increasing demand in fast non-destructive testing. In this project, linked to the thesis project of Dinh Liem Nguyen, we considered the problem of imaging a periodic penetrable structure from measurements of scattered electromagnetic waves. As a continuation of earlier work, we considered an electromagnetic problem for transverse magnetic waves (earlier work treats transverse electric fields), and also the full Maxwell equations. In both cases, we treat the direct problem by a volumetric integral equation approach and construct a Factorization method.

6.1.3. Inverse problems for Stokes-Brinkmann flows

Participants: Armin Lechleiter, Tobias Rienmüller.

Geometric inverse problems for flows arise for instance when conrolling pipelines and oil reservoirs. In this project, we considered the Stokes-Brinkmann equations that model, for instance, porous penetrable inclusions in a free background. The factorization method is able to characterize the inclusions from the relative Dirchlet-to-Neumann operator. Numerical examples show the feasibility of the method.

6.1.4. Inverse scattering from screens with impedance boundary conditions

Participants: Yosra Boukari, Houssem Haddar.

We are interested in solving the inverse problem of determining a screen (or a crack) from multi-static measurements of electromagnetic (or acoustic) scattered field at a given frequency. An impedance boundary condition is assumed to be verified at both faces of the screen. We extended the so-called factorization method to this setting. We also analyzed a data completion algorithm based on integral equation method for the Helmholtz equation. This algorithm is then coupled to the so-called RG-LSM algorithm to retrieve cracks inside a locally homogeneous background. This work is conducted in collaboration with F. Ben Hassen.

6.1.5. Transmission Eigenvalues and their application to the identification problem

Participants: Anne Cossonnière, Houssem Haddar, Giovanni Giorgi.

The so-called interior transmission problem plays an important role in the study of inverse scattering problems from (anisotropic) inhomogeneities. Solutions to this problem associated with singular sources can be used for instance to establish uniqueness for the imaging of anisotropic inclusions from muti-static data at a fixed frequency. It is also well known that the injectivity of the far field operator used in sampling methods is equivalent to the uniqueness of solutions to this problem. The frequencies for which this uniqueness fails are called transmission eigenvalues. We are currently developing approaches where these frequencies can be used in identifying (qualitative informations on) the medium properties. Our research on this topic is mainly done in the framework of the associate team ISIP http://www-direction.inria.fr/international/PHP/Networks/LiEA.php with the University of Delaware. A review article on the state of art concerning the transmission eigenvalue problem has been written in collaboration with F. Cakoni [24].

The main topic of the PhD thesis of A. Cossonnière is to extend some of the results obtained above (for the scalar problem) to the Maxwell's problem. In this perspective, theoretical results related to solutions of the interior transmission problem for medium with cavities and existence of transmission eigenvalues have been obtained [14]. This work is then extended to the case of medium with perfectly conducting inclusions. Only the scalar case has been studied [35]. In collaboration with M. Fares and F. Collino from CERFACS we investigated the use of a surface integral equation approach to find the transmission eigenvalues for inclusions with piecewise constant index. The main difficulty behind this procedure is the compactness of the obtained integral operator in usual Sobolev spaces associated with the forward scattering problem. We solved this difficulty by introducing a preconditioning operator associated with a "coercive" transmission problem. The obtained procedure has been validated numerically in 2D and 3D cases. We also analyzed the transmission eigenvalue problem using this surface integral equation approach. This technique allowed us to generalize discretness results on the spectrum to cases where the contrast can change sign [2].

With G. Giorgi, we developed a method that give estimates on the material properties using the first transmission eigenvalue. This method is based on reformulating the interior transmission eigenvalue problem into an eigenvalue problem for the material coefficients. We validated our methodology for homogeneous and inhomogeneous inclusions and backgrounds. We also treated the case of a background with absorption and the case of scatterers with multiple connected components of different refractive indexes [26].

6.1.6. *The factorization method for EIT with inhomogeneous background*

Participants: Giovanni Migliorati, Houssem Haddar.

We developed a numerical inversion scheme based on the Factorization Method to solve the (continuous model of) Electrical Impedance Tomography problem with inhomogeneous background. The numerical scheme relies on the well chosen approximation by the finite element method of the solution to the dipole-like Neumann boundary-value problem. Two regularization techniques are tested, i.e. the Tikhonov regularization embedding Morozov principle, and the classical Picard Criterion. The numerical analysis of the method and the results obtained are presented in the INRIA report [28].

6.2. Iterative Methods for Non-linear Inverse Problems

6.2.1. *Inverse medium problem for axisymmetric eddy current models*

Participants: Houssem Haddar, Zixian Jiang, Armin Lechleiter.

We are interested in shape optimization methods for inclusion detection in an axisymmetric eddy current model. This problem is motivated by non-destructive testing methodologies for steam generators. We investigated the validity of the eddy current model for these kinds of problems and developed numerical methods for the solution of the direct problem in weighted Sobolev spaces. Then we computed the shape derivative of an inclusion which allows to use regularized iterative methods to solve the inverse problem [23]. We also develop asymptotic models to identify thin highly conducting deposits.

6.2.2. *Hybrid methods for inverse scattering problems*

Participants: Grégoire Allaire, Houssem Haddar, Dimitri Nicolas.

It is well admitted that optimization methods offer in general a good accuracy but are penalized by the cost of solving the direct problem and by requiring a large number of iterations due to the ill-posedness of the inverse problem. However, profiting from good initial guess provided by sampling methods these method would become viable. Among optimization methods, the Level Set method seems to be well suited for such coupling since it is based on capturing the support of the inclusion through an indicator function computed on a cartesian grid of probed media. Beyond the choice of an optimization method, our goal would be to develop coupling strategies that uses sampling methods not only as an initialization step but also as a method to optimize the choice of the incident (focusing) wave that serves in computing the increment step.

We investigated a coupling approach between the level set method and LSM where the initialization is done using a crude estimate provided by the linear sampling method. The obtained results validate the efficiency of this coupling in the case of simply and multiply connected obstacles that are well separated.

6.3. Shape and topology optimization

6.3.1. Incorporating manufacturing constraints in topology optimization

Participant: Grégoire Allaire.

With G. Michailidis and F. Jouve we study how to incorporate manufacturing constraints in topology optimization of structures using the level set method. The goal is to obtain a structure with optimal mechanical behaviour, which at the same time respects some predefined constraints imposed by the fabrication process. In this way, the final optimal shape is manufacturable and thus the method of shape and topology optimization turns to be industrially applicable.

The first constraints we have tackled are related to the limits of thickness a structure is forced to respect. We need to avoid optimal shape that contain very thin or thick members or even members that are very close between them. To achieve this, we have adopted two different approaches, a geometrical and a mechanical one. In the geometrical one, we have made extensive use of the notion of the signed-distance function to a domain. We have formulated a global constraint which guarantees that, at the end of the optimization process, the optimal structure respects the thickness limits. In the mechanical approach, we have tried to simulate the solidification process of a structure constructed via casting. We have set a time contraint, i.e. we have required that the structure cools earlier than some predefined time limit. We have started working on a more complicated thermal equation, a non-linear model with phase change, in order to describe more accurately the solidification process.

6.3.2. Optimization of composite materials draping

Participant: Grégoire Allaire.

With G. Delgado we work on the optimization of composite materials draping. These composite structures are constructed by lamination of a sequence of unidirectional reinforced layers or plies. Each ply is typically a thin sheet of carbon fibers impregnated with polymer matrix material. The optimization variables are the geometries of these layers and they are parameterized by a level set function. In a first instance, we treat the problem of mass minimization (with a constraint on the maximal compliance) for a cantilever type composite structure, laminated with four layers of a given orthotropic material at different angles. The elasticity analysis is performed with the software Freefem++, coupled with a C++ routine to solve, by a finite difference scheme, the evolution of the level sets.

6.3.3. A hybrid optimization method

Participant: Grégoire Allaire.

With Ch. Dapogny and P. Frey we develop a new method of geometric optimization for structures that relies on two alternative descriptions of shapes : on the one hand, they are exactly meshed so that mechanical evaluations by finite elements are accurate ; on the other hand, we resort to a level-set characterization to describe their deformation along the shape gradient. The key ingredient is a meshing algorithm for building a mesh, suitable for numerical computations, out of a piecewise linear level-set function on an unstructured mesh. Therefore, our approach is at the same time a geometric optimization method (since shapes are exactly meshed) and a topology optimization method (since the topology of successive shapes can change thanks to the power of the level-set method). Our first results in 2-d have been announced. We continue to work on the 3-d case.

6.3.4. DeHomogenization

Participant: Olivier Pantz.

In most shape optimization problems, the optimal solution does not belong to the set of genuine shapes but is a composite structure. The homogenization method consists in relaxing the original problem thereby extending the set of admissible structures to composite shapes. From the numerical viewpoint, an important asset of the homogenization method with respect to traditional geometrical optimization is that the computed optimal shape is quite independent from the initial guess (even if only a partial relaxation is performed). Nevertheless, the optimal shape being a composite, a post-treatment is needed in order to produce an almost optimal non-composite (i.e. workable) shape. The classical approach consists in penalizing the intermediate densities of material, but the obtained result deeply depends on the underlying mesh used and the details level is not controllable. We proposed in [40] a new post-treatment method for the compliance minimization problem of an elastic structure. The main idea is to approximate the optimal composite shape with a locally periodic composite and to build a sequence of genuine shapes converging toward this composite structure. This method allows us to balance the level of details of the final shape and its optimality. Nevertheless, it was restricted to particular optimal shapes, depending on the topological structure of the lattice describing the arrangement of the holes of the composite. We lifted this restriction in order to extend our method to any optimal composite structure for the compliance minimization problem in [39]. Since, the method has been improved and a new article presenting the last results is in preparation. Moreover, we intend to extend this approach to other kinds of cost functions. A first attempt, based on a gradient method, has been made. Unfortunately, it was leading to local minima. Thus a new strategy has to be worked out. It will be mainly based on the same ideas than the one developed for the compliance minimization problem, but some difficulties are still to be overcome.

6.3.5. Level-Set Method

Participant: Olivier Pantz.

We have begin to work, with Gabriel Delagado, on a new level-set optimization method, based on a gradient method. The key idea consists in computing directly the derivative of the discretized cost functions. The main advantage is that it is usually more simple to implement than the standard approach (consisting in using a discretized version of the gradient of the cost function). Moreover, the results obtained are as good or even better than the one obtained in previous works. Nevertheless, this method has its drawbacks, since the cost function is only derivable almost everywhere (the zero level-set has to be transverse to the triangulation of the mesh). It follows that convergence toward the minimum by the gradient method is not granted. To overcome this problem, we intend to use a mix-formulation for the state function. An article is in preparation on this subject.

6.3.6. Robust Optimization

Participant: Olivier Pantz.

One of the main problem in shape optimization problems is due to the fact that the gradient is never computed exactly. When the current solution is far from a local optimum, this is not a problem: even a rough approximation of the gradient enable us to exhibit a descent direction. On the contrary, when close to a local optimal, a very precise computation of the gradient is needed. We intend, with G. Delgado, to use a-posteriori error estimates evaluate the errors made on the computation of the gradient and to ensure that at each step, a genuine descent direction is used in the gradient method.

6.3.7. Optimization of a sodium fast reactor core

Participants: Grégoire Allaire, Olivier Pantz.

In collaboration with D. Schmidt, G. Allaire and E. Dombre, we apply the geometrical shape optimization method for the design of a SFR (Sodium Fast reactor) core in order to minimize a thermal counter-reaction known as the sodium void effect. In this kind of reactor, by increasing the temperature, the core may become liable to a strong increase of reactivity ρ, a key-parameter governing the chain-reaction at quasi-static states. We first use the 1 group energy diffusion model and give the generalization to the 2 groups energy equation. We then give some numerical results in the case of the 1 group energy equation. Note that the application of our method leads to some designs whose interfaces can be parametrized by very smooth curves which can stand very far from realistic designs. We don't explain here the method that it would be possible to use for recovering an operational design but there exists several penalization methods that could be employed to this end. This work was partially sponsored by EDF. Our results will be published in the proceedings of the CEMRACS'11, during which part of the results have been obtained.

6.4. Asymptotic models

6.4.1. Inverse scattering problem for coated obstacles

Participants: Nicolas Chaulet, Houssem Haddar.

In collaboration with L. Bourgeois, we considered the inverse scattering problem consisting in the identification of both an obstacle and its "equivalent impedance" from farfield measurements at a fixed frequency. The first specificity of this work is to consider the cases where this impedance is not a scalar function but a second order surface operator. The latter can be seen as a more general model for effective impedances and is for instance widely used for scattering from thin coatings. The second specificity of this work is to characterize the derivative of a least square cost functional with respect to this complex configuration. We provide in particular an extension of the notion of shape derivative to the cases where the impedance parameters cannot be considered as the traces of given functions. For instance, the obtained derivative does not vanish (in general) for tangential perturbations. The efficiency of considering this type of derivative is illustrated by some 2D numerical experiments based on a (classical) steepest descent method. The feasibility of retrieving both the obstacle and the impedance functionals is discussed in further numerical experiments [33].

6.4.2. Interface conditions for thin dielectrics

Participant: Houssem Haddar.

Jointly with B. Delourme and P. Joly we established transmission conditions modelling thin interfaces that has (periodic) rapid variations along tangential coordinates. Motivated by non destructive testing experiments, we considered the case of cylindrical geometries and time harmonic waves. We already obtained a full asymptotic description of the solution in terms of the thickness in the scalar case using so called matched asymptotic expansions. This asymptotic expansion is then used to derive generalized interface conditions and establish error estimates for obtained approximate models [15]. The analysis of the approximate problem for Maxwell's equations is the subject of a forthcoming publication.

6.4.3. Homogenization

Participant: Grégoire Allaire.

With I. Pankratova and A. Piatnitski we considered the homogenization of a non-stationary convection-diffusion equation posed in a bounded periodic heterogeneous domain with homogeneous Dirichlet boundary conditions. Assuming that the convection term is large, we give the asymptotic profile of the solution and determine its rate of decay. In particular, it allows us to characterize the "hot spot", i.e., the precise asymptotic location of the solution maximum which lies close to the domain boundary and is also the point of concentration. Due to the competition between convection and diffusion, the position of the "hot spot" is not always intuitive as exemplified in some numerical tests.

With Z. Habibi we studied the homogenization of heat transfer in periodic porous media where the fluid part is made of long thin parallel cylinders, the diameter of which is of the same order than the period. The heat is transported by conduction in the solid part of the domain and by conduction, convection and radiative transfer in the fluid part (the cylinders). A non-local boundary condition models the radiative heat transfer on the cylinder walls. To obtain the homogenized problem we first use a formal two-scale asymptotic expansion method. The resulting effective model is a convection-diffusion equation posed in a homogeneous domain with homogenized coefficients evaluated by solving so-called cell problems where radiative transfer is taken into account. In a second step we rigorously justify the homogenization process by using the notion of two-scale convergence. One feature of this work is that it combines homogenization with a 3D to 2D asymptotic analysis since the radiative transfer in the limit cell problem is purely two-dimensional. Eventually, we provide some 3D numerical results in order to show the convergence and the advantages of our homogenization method.

6.4.4. *Modelling and simulation for underground nuclear waste storage.*

Participants: Grégoire Allaire, Harsha Hutridurga.

In the framework of the GDR MOMAS (Groupement de Recherches du CNRS sur les MOdélisations MAthématiques et Simulations numériques liées aux problèmes de gestion des déchets nucléaires) I am working with R. Brizzi, H. Hutridurga, A. Mikelic and A. Piatnitski on upscaling of microscopic models by homogenization (i.e. finding macroscopic models and effective coefficients).

We studied the Taylor dispersion of a contaminant in a porous medium. The originality of the model is that it takes into account surface diffusion and convection on the pores boundaries. We rigorously obtained the homogenized equation and studied the behavior of the effective dispersion tensor when varying various parameters.

In collaboration with a team of chemists (around J.-F. Dufrêche from the GNR Paris), we have undertaken the rigorous homogenization of a system of PDEs describing the transport of a N-component electrolyte in a dilute Newtonian solvent through a rigid porous medium. The motion is governed by a small static electric field and a small hydrodynamic force, which allowed us to use O'Brien's linearized equations as the starting model. Convergence of the homogenization procedure was established and the homogenized equations were discussed. Based on the rigorous study of the underlying equations, it was proved that the effective tensor satisfies Onsager properties, namely is symmetric positive definite. This result justified the approach of many authors who used Onsager theory as a starting point.

6.4.5. *A new membrane/plate modeling*

Participant: Olivier Pantz.

Using a formal asymptotic expansion, we have proved with K. Trabelsi, that non-isotropic thin-structure could behave (when the thickness is small) like a shell combining both membrane and bending effects. It is the first time to our knowledge that such a model is derived. An article on this project is in preparation.

6.4.6. *A new Liouville type Rigidity Theorem*

Participant: Olivier Pantz.

We have recently developed a new Liouville type Rigidity Theorem. Considering a cylindrical shaped solid, we prove that if the local area of the cross sections is preserved together with the length of the fibers, then the deformation is a combination of a planar deformation and a rigid motion. The results currently obtained are limited to regular deformations and we are currently working with B. Merlet to extend them. Nevertheless, we mainly focus on the case where the conditions imposed to the local area of the cross sections and the length of the fibers are only "almost" fulfilled. This will enable us to derive rigorously new non linear shell models combining both membranar and flexural effects that we have obtained using a formal approach.

6.4.7. *Lattices*

Participant: Olivier Pantz.

With A. Raoult and N. Meunier (Université Paris Descartes), we have compute the asymptotic limit of a square lattice with three-points interactions. An article currently under review has been submitted on this work.

6.4.8. Homogenization of axon Bundles

Participant: Olivier Pantz.

With E. Mandonnet (Lariboisière Hospital), we have developed a new modeling for bundles of axons using homogenization technique. Previous works only focus (even if not explicitly) in the low density case: That is when the axon density is small. The aim is to determine which kind of electrical stimulation could trigger a signal into the axon. Under the low density assumption, the external electric field is independent of the membrane potential of the axon. If not, both are strongly coupled. Moreover, we have performed numerical simulations to determine what is the best position of the electrodes to enable the activation of the axons. This work has lead to the publications of an article [20] and a technical report [29]. Finally, we have begin to investigate more realistic modelings of the ionic flux based on the works of FitzHuch-Nagumo with a student, Xinxin Cheng, who spend three months at the CMAP.

6.5. Diffusion MRI

6.5.1. Homogenized diffusion tensor and approximate analytical formulae for the long time ADC

Participants: Jing-Rebecca Li, Houssem Haddar.

We model the bulk magnetization in biological tissue due to a diffusion gradient at the voxel level by a two compartment Bloch-Torrey partial differential equation. The cell membranes are modelled as infinitely thin permeable interfaces. We show the simulated long time apparent diffusion tensor of the PGSE sequence is close to the effective diffusion tensor from homogeneization theory for both isotropic and anisotropic diffusion. For nearly isotropic diffusion we give analytical approximate formulae for the long time apparent diffusion coefficient in two and three dimensions. The approximate formulae allow us to robustly estimate the change in the cellular volume fraction from ADC measurements before and after cell swelling if the cells are approximately uniform in size. We can also use the formulae to estimate the average cell size.

6.5.2. General ODE model of diffusion MRI signal attenuation

Participants: Jing-Rebecca Li, Hang Tuan Nguyen.

We model the magnetization in biological tissue due to a diffusion gradient by a two compartment Bloch-Torrey partial differential equation with infinitely thin permeable membranes. We formulate a ODE model for the magnetization and show the simpler ODE model is a good approximation to the Bloch-Torrey PDE model for a variety of gradient shapes. Using the ODE model we determine of the change in the cellular volume fraction from the signal attenuation obtained before and after cell swelling. This method requires only the ADC and Kurtosis of the two signal attenuations and the numerical solution of an ODE system.

7. Contracts and Grants with Industry

7.1. RODIN project

Participant: Grégoire Allaire.

Launching of the RODIN project (Robust Optimal Design in INdustry) in 2011 with EADS IW, Renault, ESI Group, Eurodecision, Ecole Polytechnique, Paris 6 University, INRIA. One of the aims of the RODIN project is to develop a new shape optimization software for solid structures in the framework of the SYSTUS code developed by ESI-group.

7.2. ANR, Program COSINUS, 2010-2013

Participants: Jing-Rebecca Li, Houssem Haddar, Armin Lechleiter.

We obtained 200Keuros grant from ANR, program Cosinus, 2010-2013. J.R. Li is the coordinator of this project: "Simulation du signal d'IRM diffusion dans des tissus biologiques (SIMUDMRI)", which is a joint proposal between INRIA-Saclay (Coordinator) and CEA Neurospin.

http://www.cmap.polytechnique.fr/~jingrebeccali/grants/simudmri.html

7.3. ANR, Program MN, 2011-2014

Participants: Houssem Haddar, Armin Lechleiter.

We obtained a 220Keuros from ANR, program MN, 2011-2014, in the framework of the project: Modelization and numerical simulation of wave propagation in metamaterials. This is a joint ANR with POEMS (INRIA Rocquencourt), DMIA, Département de Mathématiques de l'ISAE and IMATH, Laboratoire de Mathématiques de l'Université de Toulon. https://www.rocq.inria.fr/poems/metamath

7.4. EDF R&D, 2010-2013

Participants: Houssem Haddar, Armin Lechleiter, Zixian Jiang.

We have partnership grant with STEP department of EDF R&D on non destructive testing using eddy current probes. This grant covers the expenses of the PhD thesis of Zixian Jiang.

7.5. PEPS (CNRS short grant), 2011

Participant: Grégoire Allaire.

PEPS (CNRS short grant) with EDF on optimal design of nuclear reactor cores. This grant covered the expenses of a sixth month internship (Master M2).

7.6. PhD advising

Participant: Grégoire Allaire.

Contracts covering PhD advising (Thèses CIFRE) with EADS, IFP and Renault (2011-2013).

8. Partnerships and Cooperations

8.1. National Actions

- The DeFI group participates to the EADS-X-INRIA Chair: Mathematical Modeling and Numerical Simulation (MMNS): `http://www.cmap.polytechnique.fr/mmnschair/home.html` created on 2008 for at leat 4 years and with a total budget of 1 million euros. G. Allaire is the leader of this Chair.
- G. Allaire participates to the GDR MOMAS

8.2. European Initiatives

8.2.1. Collaborations in European Programs, except FP7

Program: PHC PROCOPE

Project acronym: ISTD

Project title: Inverse scattering in the time domain

Duration: 09/2010 - 09/2012

Coordinator: A. Lechleiter

Other partners: University of Goettingen, Department of Math. (Germany)

Abstract: Develop MuSiC type algorithm for inverse scattering problems in time domain.

8.2.2. Major European Organizations with which you have followed Collaborations

Partner 1: University of Goettingen, Department of Math. (Germany)

Development of conformal mapping method to electrostatic inverse problems. Correspondant: Rainer Kress.

Partner 2: University of Genova, Department of Math. (Italy)

Development of qualitative methods in inverse scattering problems. Correspondant: Michele Piana.

8.3. International Initiatives

8.3.1. INRIA Associate Teams

8.3.1.1. ISIP

Title: Inverse Scattering and Identification Problems

INRIA principal investigator: Houssem HADDAR

International Partner:

Institution: University of Delaware (United States)

Laboratory: Mathematical Department

Duration: 2008 - 2013

See also: http://www.cmap.polytechnique.fr/~defi/ISIP/isip.html

The associated team concentrates on the use of qualitative methods in electromagnetic inverse scattering theory with applications to the imaging of urban infrastructure, the nondestructive evaluation of coated materials and medical imaging. Most of the effort is focused in the solution of the inverse problems using time harmonic waves, in particular for frequencies in the resonance regime.

8.3.2. Visits of International Scientists

Prof. F. Cakoni (University of Delaware, USA) visited the DEFI team from September 15th till December 15th 2011 during her sabbatical semester. Her stay was supported by CNRS and the associated team ISIP.

Prof. D. Colton (University of Delaware, USA) visited the DEFI team one weak in June and one weak in November 2011. His stay was supported by the ISIP associated team.

Dr. Fahmi Ben Hassen (LAMSIN, Tunisia) visted the DEFI team two weaks in March 2011.

Dr. Givanni Giorgi (University of Genova, Italy) visited the DEFI team during three months (February-April) in 2011.

Dr. Ozgur Ozdemir (Istanbul Technical University, Turkey) visited the DEFI team two weaks in August 2011.

9. Dissemination

9.1. Animation of the scientific community

- Gregoire Allaire
Vice-president of the applied mathematics department at Ecole Polytechnique.
Member of the board of SMAI (Société de Mathématiques Appliquées et Industrielles).
Member of the managing committe of GAMNI/SMAI (Groupement pour l'Avancement des Méthodes Numériques pour l'Ingénieur).
Chair of the Scientific Council of GDR MOMAS (MOdélisations MAthématiques et Simulations numériques liées aux problèmes de gestion des déchets nucléaires).
Member of the board of IHP (Institut Henri Poincaré).
Member of the Scientific Council of GDR Calcul.
Co-editor in chief of the series "Mathématiques et Applications" published by Springer and SMAI.
Member of the editorial boards of ESAIM/COCV, Structural and Multidisciplinary Optimization, Discrete and Continuous Dynamical Systems Series B, Computational and Applied Mathematics, Mathematical Models and Methods in Applied Sciences (M3AS),
Annali dell'Universita di Ferrara.
Co-organizer of the annual CEA/GAMNI seminar on computational fluid dynamics (January 2011).
Organizer of the workshop "mathematics and mechanics" at the French Congress of Mechanics in Besan con (August 2011).
Co-organizer of the MOMAS workshop in Luminy (November 2011).
- Houssem Haddar
Member of CNU 26, INSA, Toulouse.
Member of the Scientific committees at INRIA Saclay Ile de France and at CMP.
Organizer of a minisymposium at AIP 2011 and participates to the board committee of Waves 2011.
- Jing-Rebecca Li
Associate editor of SIAM Journal on Scientific Computing.
Organizer of mini-symposium "Advances in applied numerical methods for complex applications", ICIAM 2011, 7th International Congress on Industrial and Applied Mathematics.
Non-specialist talk in Unithe ou Cafe series, "Les molecules n'en font qu'a leur tete Mots-cles valides : cerveau, IRM, maladies, diffusion", March 11, 2011.

9.2. Teaching

Licence: Grégoire Allaire teaches a semestrial course (18 lectures) on numerical analysis and optimization (L3). Ecole Polytechnique, France.

Master: Grégoire Allaire teaches two courses (9 lectures each) (M1). The first one on the optimal design of structures ; The second one is taught in collaboration with François Golse on transport and diffusion with aplications to energy and biology. Ecole Polytechnique, France.

Master: Grégoire Allaire teaches a semestrial course (12 lectures) on homogenization (M2). Ecole Polytechnique, France.

Master: Armin Lechleiter, MODAL MAP441 (54hours, responsible: François Alouges). Supervision of two projects in pairs (M2). Ecole Polytechnique, France.

Licence (ou équivalent) : Houssem Haddar teaches a semestrial course (18 lectures) on numerical analysis and optimization (L3). Ecole Polytechnique, France.

Master (ou équivalent) : Houssem Haddar teaches one course (9 lectures) (M2 Ecole Polytechnique) on Mathematics of inverse problems.

Licence: Olivier Pantz teaches a semestrial course (36 lectures) on numerical analysis and optimization (L3). Ecole Polytechnique, France.

Master: Olivier Pantz teaches one course (7 lectures) (M1) on the optimal design of structures, Ecole Polytechnique, France.

Master: Olivier Pantz was responsible of a project training in Numerical Analysis (1 project - “Stimulation des neurones par une électrode”)

PhD: Olivier Pantz, WorkshopFreeFem++ (Université Pierre et Marie-Curie) An Introduction course in FreeFem++ and computer session.

PhD: Olivier Pantz, FreeFem++ course at the LERMA of the EMI (Rabat) (1 week: course and computer sessions)

9.3. PhD & HdR

PhD : Anne Cossonnière, Transmission eigenvalues and their use in the identification of inclusions from electromagnetic measurements, INSA Toulouse, 8/12/2011, Houssem Haddar and Anne Sophie Bonnet Ben-Dhia

PhD : Thomas Abballe, Multi-scale numerical methods for diffusion in heterogeneous media, Ecole Polytechnique, 24/06/2011, Grégoire Allaire.

PhD : Iryna Pankratova, Homogenization of singular convection-diffusion equations and indefinite spectral problems, 17/01/2011, Grégoire Allaire.

PhD : Zakaria Habibi, Homogenization for thermal transfers in nuclear reactor cores, Ecole Polytechnique, 16/12/2011, Grégoire Allaire.

PhD in progress : Y. Boukari, Qualitative Methods for Inverse Scattering by an Impedant Crack, 2008 (Defense in January 2012), Houssem Haddar (with Fahmi Ben Hassen).

PhD in progress : M. Chamaillard, Asymptotic models for periodic interfaces, 2011, Houssem Haddar (with Patrick Joly).

PhD in progress : N. Chaulet, Inverse scattering problems for obstacles with non standard impedance models, 2009, Houssem Haddar (with Laurent Bourgeois).

PhD in progress : Ch. Dapogny, Geometric shape optimization, 2010, Grégoire Allaire (with Pascal Frey).

PhD in progress : G. Delgado, Optimal design of the draping of composite materials, 2010, Grégoire Allaire.

PhD in progress : G. Giovanni, Mathematical tools for microwave mammography and prostate cryosurgery, 2008 (Defense in January 2012), Houssem Haddar (with Michele Piana).

PhD in progress : H. Hutridurga, Homogenization of reactive flows in porous media, 2010, Grégoire Allaire.

PhD in progress : Z. Jiang, Non linear optimization methods applied to non destructive testing using eddy current probes, 2010, Houssem Haddar.

PhD in progress : G. Michailidis, on topology optimization with feasibility constraints, 2010, Grégoire Allaire (with Francois Jouve).

PhD in progress : G. Migliorati, Qualitative methods for random backgrounds, 2011, Houssem Haddar (with Fabio Nobile).

PhD in progress : D. Nicolas, Shape optimization methods for inverse problem, 2009, Grégoire Allaire (with Houssem Haddar).

PhD in progress : D. V. Nguyen, Efficient finite-element method to solve PDE problems in diffusion MRI, 2011, Jing-Rebecca Li (with Denis Grebenkov).

PhD in progress : H. T. Nguyen, Simplified models and inverse problems for diffusion MRI, , 2011, Jing-rebecca Li (with Denis Grebenkov and Cyril Poupon).

PhD in progress : D. L. Nguyen, Direct and inverse scattering problem for periodic gratings, 2009, Houssem Haddar and Armin Lechleiter.

PhD in progress : F. Ouaki, on multi-scale numerical methods for multiphasic transport in porous media, 2010, Gregoire Allaire.

9.4. Seminars, Conferences, Visits

G. Allaire

- Invited conference at the 10th "GAMM-Seminar on Microstructures", Darmstadt (January 2011).
- Invited conference at the MATCH colloquium "Analytical and numerical methods for multi-scale systems", Heidelberg (February 2011).
- Conference at the GNR PARIS workshop (physico-chemistry for the nuclear waste storage), Paris (March 2011).
- Invited conference at "the mathematics of porous media (in honour of H. van Duijn)", Split (June 2011).
- Speaker at the conference "Applied mathematics and scientific computing", Trogir (June 2011).
- Speaker at the workshop "Current Problems in Solid Mechanics (in honour of H.D. Bui)", Paris (July 2011).
- Invited conference at "Inverse Problems and Applications", Ecole Polytechnique (September 2011).
- Euromech workshop "Recent Trends in Optimization for computational Solid Mechanics" Erlangen (October 2011).
- Journées scientifiques MOMAS, Luminy (November 2011).
- Seminar at BCAM, Bilbao (November 2011).

Y. Boukari

- Talk at WAVES'11, Vancouver, July 25-29, 2011.
- Talk at the workshop Tendances dans les Applications Mathématiques en Tunisie, Algérie, Maroc (TAM TAM), Sousse (Tunisie), April 2011.
- Talk at the AIP Conference, May 2011, College Station, US.

N. Chaulet

- Talk in the minisymposium on *Shape reconstruction in impedance tomography and inverse scattering* at ICIAM 2011 conference in Vancouver in juillet 2011.
- Talk at WAVES'11, Vancouver, July 25-29, 2011.
- Invited talk at *Journée sur les problèmes inverses* in November 2011, Annaba, Algeria.

A. Cossonnière

- Invited, minisymposium PIERS in Marrakesh, March 20-23, 2011.
- Talk at WAVES'11, Vancouver, July 25-29, 2011.
- Poster at COFREN, Dunkerque, May 24-27 2011.

H. Haddar

- Invited, minisymposium PIERS in Marrakesh, March 20-23, 2011.
- Organized a minisymposium *Advances in qualitative methods* at the AIP Conference, May 2011, College Station, US.
- Invited conference, LERMA 20th birthday conference.

- Participation (organisation) WAVES'11, Vancouver, July 25-29, 2011
- Invited conference at "Inverse Problems and Applications", Ecole Polytechnique (September 2011).
- Invited seminar, 25 November 2011, University of Cergy Pontoise.

Z. Jiang

- Poster at 2011 European Signal Processing Conference (EUSIPCO 2011), CTTC & UPC, Barcelona, Spain, 2011
- Poster at Workshop on Numerical Electromagnetics and Industrial Applications (NELIA 2011), Faculty of Mathematics of Saint Jacques de Compostella (Spain), October 2011.

A. Lechleiter

- Talk at the Oberwolfach Miniworkshop "Nonlinear Least Squares in Shape Identification Problems", Oberwolfach, Germany, January 2011.
- Talk in the minisymposium *Shape reconstruction in impedance tomography and inverse scattering* the AIP Conference, May 2011, College Station, US.
- Talk in the minisymposium *Advances on Numerical Methods for Electrical Impedance Tomography* at the Fields-MITACS Conference on Mathematics of Medical Imaging, Toronto, Canada, June 2011.
- Talk at at WAVES'11, Vancouver, July 25-29, 2011.
- Invited talk at the Newton Institute's workshop *Inverse Problems in Analysis and Geometry*, Cambridge, UK, August 2011.
- Invited seminar of the math department, Metz, France, October 2011.

J.-R. Li

- The International Society for Magnetic Resonance in Medicine (ISMRM) annual meeting, Montreal, May, 2011.
- Mini-symposium "Advances in applied numerical methods for complex applications", ICIAM 2011, 7th International Congress on Industrial and Applied Mathematics.

G. Migliorati

- Workshop on Large-scale inverse problems and quantification of uncertainty, IMA-University of Minnesota (USA), June 6-10 2011.
- Workshop on Wave Propagation and Scattering, Inverse Problems and Applications in Energy and the Environment, Linz(Austria), November 21-25, 2011.
- Workshop on Numerical Analysis of Multiscale Problems and Stochastic Modelling, Linz (Austria), December 12-16, 2011.

D. Nicolas

- Talk at WAVES'11, Vancouver, July 25-29, 2011.

D. L. Nguyen

- Talk at WAVES'11, Vancouver, July 25-29, 2011.

O. Pantz

- "Treatment of contacts and self-contacts with FreeFem++" Journees FreeFem++, UPMC (December 2011)
- Participation to the workshop "Multiscale Coupling of Complex Models" CEMRACS'11, Luminy (August 2011)

– "The modeling of contacts and self-contacts for finite deformations" Tunis (May 2011)

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] T. ABBALLE. *Multi-scale numerical methods for diffusion in heterogeneous media*, Ecole Polytechnique, Juin 2011.

[2] A. COSSONNIÈRE. *Transmission eigenvalues and their use in the identification of inclusions from electromagnetic measurements*, INSA Toulouse, December 2011.

[3] Z. HABIBI. *Homogenization for thermal transfers in nuclear reactor cores*, Ecole Polytechnique, December 2011.

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Articles in International Peer-Reviewed Journal

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