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Project-Team DEFI

Shape reconstruction and identification

IN COLLABORATION WITH: Centre de Mathématiques Appliquées (CMAP)

RESEARCH CENTER
Saclay - Île-de-France

THEME
Numerical schemes and simulations

Table of contents

Project-Team DEFI

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Creation of the Project-Team: 2009 January 01.

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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.

During the last four years we were particularly interested in the development of the following themes that will be presented in details later.

- Qualitative methods for inverse scattering problems
- Iterative and Hybrid inversion methods
- Topological optimization methods
- Direct and inverse models for Diffusion MRI
- Asymptotic models and methods for waves and diffusion.

3. Research Program

3.1. Research Program

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 (topological) 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, ultrasound, X-ray tomography, etc.), that rely on one of these approximations.

Generally speaking, the used simplifications result in 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 multi-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 cartesian 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 called “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.

A broader perspective 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.

For the identification problem, one would like to also have information on 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. We also refer here to the use of so called transmission eigenvalues as qualitative indicators for non destructive testing of dielectrics.

We are also interested in parameter identification problems arising in diffusion-type problems. Our research here is mostly motivated by applications to the imaging of biological tissues with the technique of Diffusion Magnetic Resonance Imaging (DMRI). Roughly speaking 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. The main challenges here are 1) correctly model measured signals using diffusive-type time-dependent PDEs 2) numerically handle the complexity of the tissues 3) use the first two to identify physically relevant parameters from measurements. For the last point we are particularly interested in constructing reduced models of the multiple-compartment Bloch-Torrey partial differential equation using homogenization methods.

4. Application Domains

4.1. Radar and GPR applications

Conventional radar imaging techniques (ISAR, GPR, etc.) 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

In biological tissues, water is abundant and magnetic resonance imaging (MRI) exploits the magnetic property of the nucleus of the water proton. The imaging contrast (the variations in the grayscale in an image) in standard MRI can be from either proton density, T1 (spin-lattice) relaxation, or T2 (spin-spin) relaxation and the contrast in the image gives some information on the physiological properties of the biological tissue at different physical locations of the sample. The resolution of MRI is on the order of millimeters: the greyscale value shown in the imaging pixel represents the volume-averaged value taken over all the physical locations contained that pixel.

In diffusion MRI, the image contrast comes from a measure of the average distance the water molecules have moved (diffused) during a certain amount of time. The Pulsed Gradient Spin Echo (PGSE) sequence is a commonly used sequence of applied magnetic fields to encode the diffusion of water protons. The term 'pulsed' means that the magnetic fields are short in duration, an the term gradient means that the magnetic fields vary linearly in space along a particular direction. First, the water protons in tissue are labelled with nuclear spin at a precession frequency that varies as a function of the physical positions of the water molecules via the application of a pulsed (short in duration, lasting on the order of ten milliseconds) magnetic field. Because the precessing frequencies of the water molecules vary, the signal, which measures the aggregate phase of the water molecules, will be reduced due to phase cancellations. Some time (usually tens of milliseconds) after the first pulsed magnetic field, another pulsed magnetic field is applied to reverse the spins of the water molecules. The time between the applications of two pulsed magnetic fields is called the 'diffusion time'. If the water molecules have not moved during the diffusion time, the phase dispersion will be reversed, hence the signal loss will also be reversed, the signal is called refocused. However, if the molecules have moved during the diffusion time, the refocusing will be incomplete and the signal detected by the MRI scanner if weaker than if the water molecules have not moved. This lack of complete refocusing is called the signal attenuation and is the basis of the image contrast in DMRI. the pixels showning more signal attenuation is associated with further water displacement during the diffusion time, which may be linked to physiological factors, such as higher cell membrane permeability, larger cell sizes, higher extra-cellular volume fraction.

We model the nuclear magnetization of water protons in a sample due to diffusion-encoding magnetic fields 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) and provides the most commonly used form the image contrast for DMRI. This ADC is closely related to the effective diffusion coefficient obtainable from mathematical homogenization theory.

5. New Software and Platforms

5.1. RODIN

Participant: Grégoire Allaire [correspondant].

In the framework of the RODIN project we continue to develop with our software partner ESI the codes Topolev and Geolev for topology and geometry shape optimization of mechanical structures using the level set method.

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. Eddy current problems

Participants: Zixian Jiang, Mohamed Kamel Riahi.

We developed a FreeFem++ toolbox that solves direct and inverse problems for an axisymmetric and 3D eddy current problems related to non destructive testing of deposits on the shell side of PWR fuel tubes. For the 3-D version, one can refer to http://www.cmap.polytechnique.fr/~riahi and also to [15].

5.2.3. 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.

5.2.4. 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: http://www.cmap.polytechnique.fr/~allaire/levelset_en.html

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. The latest development includes the extension of the method to the inverse scattering problem at low frequencies as introduced by Haddar-Kress (2012).

5.3.3. SAXS Utilities

Participants: Federico Benvenuto [correspondant], Houssem Haddar.

We developed a scilab and matlab toolboxes that post treat SAXS type measurements to identify size distributions of diluted particles. We treat both axisymmetric measuremenst and anisotropic ones. The toolbox also simulates SAXS measurements associated with some canonical geometries.

5.3.4. Direct Solver for periodic media

Participants: Thi Phong Nguyen [correspondant], Houssem Haddar.

This Matlab toolbox solves the scattering from locally perturbed periodic layer using Floquet-Bloch transform and spectral discretization of associated volume integral equation.

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

Participant: Houssem Haddar [correspondant].

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.

5.5. BlochTorreyPDESolver

Participants: Jing-Rebecca Li [correspondant], Dang Van Nguyen.

We developed two numerical codes to solve the multiple-compartments Bloch-Torrey partial differential equation in 2D and 3D to simulate the water proton magnetization of a sample under the influence of diffusion-encoding magnetic field gradient pulses.

We coupled the spatial discretization with an efficient time discretization adapted to diffusive problems called the (explicit) Runge-Kutta-Chebyshev method.

The version of the code using Finite Volume discretization on a Cartesian grid is complete (written by Jing-Rebecca Li). The version of the code using linear Finite Elements discretization is complete (written by Dang Van Nguyen and Jing-Rebecca Li).

See the web page http://www.cmap.polytechnique.fr/~jingrebeccali/ for more details.

6. New Results

6.1. Qualitative methods for inverse scattering problems

6.1.1. Identifying defects in an unknown background using differential measurements

Participants: Lorenzo Audibert, Houssem Haddar.

With Alexandre Girard, we developed a new qualitative imaging method capable of selecting defects in complex and unknown background from differential measurements of farfield operators: i.e. far measurements of scattered waves in the cases with and without defects. Indeed, the main difficulty is that the background physical properties are unknown. Our approach is based on a new exact characterization of a scatterer domain in terms of the far field operator range and the link with solutions to so-called interior transmission problems. We present the theoretical foundations of the method and some validating numerical experiments in a two dimensional setting [10]. This work is based on the generalized formulation of the Linear Sampling Method with exact characterization of targets in terms of farfield measurements that has been introduced in [1].

6.1.2. The Factorization Method for a Cavity in an Inhomogeneous Medium

Participants: Houssem Haddar, Shixu Meng.

With F. Cakoni we considered the inverse scattering problem for a cavity that is bounded by a penetrable anisotropic inhomogeneous medium of compact support where on is interested in determining the shape of the cavity from internal measurements on a curve or surface inside the cavity. We derived a factorization method which provides a rigorous characterization of the support of the cavity in terms of the range of an operator which is computable from the measured data. The support of the cavity is determined without a-priori knowledge of the constitutive parameters of the surrounding anisotropic medium provided they satisfy appropriate physical as well as mathematical assumptions imposed by our analysis. Numerical examples were given showing the viability of our method [7].

6.1.3. Asymptotic analysis of the transmission eigenvalue problem for a Dirichlet obstacle coated by a thin layer of non-absorbing media

Participant: Houssem Haddar.

With F. Cakoni and N. Chaulet we considered the transmission eigenvalue problem for an impenetrable obstacle with Dirichlet boundary condition surrounded by a thin layer of non-absorbing inhomogeneous material. We derived a rigorous asymptotic expansion for the first transmission eigenvalue with respect to the thickness of the thin layer. Our convergence analysis is based on a Max–Min principle and an iterative approach which involves estimates on the corresponding eigenfunctions. We provided explicit expressions for the terms in the asymptotic expansion up to order 3 [3].

6.1.4. Boundary Integral Equations for the Transmission Eigenvalue Problem for Maxwell's Equations

Participants: Houssem Haddar, Shixu Meng.

In this work, we considered the transmission eigenvalue problem for Maxwell's equations corresponding to non-magnetic inhomogeneities with contrast in electric permittivity that changes sign inside its support. Following the approach developed by Cossonnière-Haddar in the scalar case, we formulate the transmission eigenvalue problem as an equivalent homogeneous system of boundary integral equation and prove that assuming that the contrast is constant near the boundary of the support of the inhomogeneity, the operator associated with this system is Fredholm of index zero and depends analytically on the wave number. Then we show the existence of wave numbers that are not transmission eigenvalues which by an application of the analytic Fredholm theory implies that the set of transmission eigenvalues is discrete with positive infinity as the only accumulation point. This is a joint work with F. Cakoni.

6.1.5. Invisibility in scattering theory

Participant: Lucas Chesnel.

We investigated a time harmonic acoustic scattering problem by a penetrable inclusion with compact support embedded in the free space. We considered cases where an observer can produce incident plane waves and measure the far field pattern of the resulting scattered field only in a finite set of directions. In this context, we say that a wavenumber is a non-scattering wavenumber if the associated relative scattering matrix has a non trivial kernel. Under certain assumptions on the physical coefficients of the inclusion, we showed that the non-scattering wavenumbers form a (possibly empty) discrete set. This result is important in the justification of certain reconstruction techniques like the Linear Sampling Method in practical applications.

In a second step, for a given real wavenumber and a given domain D, we developed a constructive technique to prove that there exist inclusions supported in D for which the corresponding relative scattering matrix is null. These inclusions have the important property to be impossible to detect from far field measurements. The approach leads to a numerical algorithm which allows to provide examples of (approximated) invisible inclusions. This is a joint work with A.-S. Bonnet-Ben Dhia and S.A. Nazarov [11].

6.1.6. Invisibility in electrical impedance tomography

Participant: Lucas Chesnel.

We adapted the technique to construct invisible isotropic conductivities in for the point electrode model in electrical impedance tomography. Again, the theoretical approach, based on solving a fixed point problem, is constructive and allows the implementation of an algorithm for approximating the invisible perturbations. We demonstrated the functionality of the method via numerical examples. This a joint work with N. Hyvönen and S. Staboulis [13].

6.1.7. A quasi-backscattering problem for inverse acoustic scattering in the Born regime

Participants: Houssem Haddar, Jacob Rezac.

In this work we propose a data collection geometry in which to frame the inverse scattering problem of locating unknown obstacles from far-field measurements of time-harmonic scattering data. The measurement geometry, which we call the quasi-backscattering set-up, is configurated such that one device acts as a transmitter and a line of receivers extends in one-dimension a small distance from the transmitter. We demonstrate that the data collected can be used to locate inhomogeneities whose physical properties are such that the Born approximation applies. In particular, we are able to image a two-dimensional projection of the location of an obstacle by checking if a test function which corresponds to a point in $\mathbb{R}^2$ belongs to the range of a measurable operator. The reconstruction algorithm is based on the MUSIC (Multiple SIgnal Classification) algorithm.

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, Mohamed Kamel Riahi.

We continued our developments of 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 finalized a joint work with A. Lechleiter on numerical methods for the solution of the direct problem in weighted Sobolev spaces using approriate Dirichlet-to-Neumann mappings to bound the computational domain. We are also finalized jointly with M. El Guedri the work on inverse solver using a regularized steepest descent method for the problem of identifying a magnetite deposits using axial eddy current probe. We addressed two issues:

- We developed asymptotic models to identify thin highly conducting deposits. We derived three possible asymptotic models that can be exploited in the inverse problem. We are about to finalize a preprint on this topic.
- We extended the inverse scheeme to 3D configurations with axisymmetry at infinity: this includes exact charactherization of the shape derivative for a mixed formulation of eddy current problems and a parametric inversion scheme based on a pre-defined discrete grid for deposit location [14].

6.2.2. The conformal mapping method and free boundary problems

Participant: Houssem Haddar.

Together with R. Kress we employed a conformal mapping technique for the inverse problem to reconstruct a perfectly conducting inclusion in a homogeneous background medium from Cauchy data for electrostatic imaging, that is, for solving an inverse boundary value problem for the Laplace equation. In a recent work we proposed an extension of this approach to inverse obstacle scattering for time-harmonic waves, that is, to the solution of an inverse boundary value problem for the Helmholtz equation. The main idea is to use the conformal mapping algorithm in an iterative procedure to obtain Cauchy data for a Laplace problem from the given Cauchy data for the Helmholtz problem. We presented the foundations of the method together with a convergence result and exhibit the feasibility of the method via numerical examples. We are currently investigating the extention of this method to solve free boundary value problems.

6.2.3. A steepest descent method for inverse electromagnetic scattering problems

Participant: Houssem Haddar.

Together with N. Chaulet, we proposed the application of a non linear optimization techniques to solve the inverse scattering problems for the $3D$ Maxwell's equations with generalized impedance boundary conditions. We characterized the shape derivative in the case where the GIBC is defined by a second order surface operator. We then applied a boundary variation method based on a regularized steepest descent to solve the 3-D inverse problem with partial farfield data. The obtained numerical results demonstrated the possibility of identifying the shape of coated objects as well as the parameters of the coating in the $3D$ Maxwell case [4].

6.2.4. A posteriori error estimates: Application to Electrical Impedance Tomography

Participants: Olivier Pantz, Matteo Giacomini.

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. Together with Karim Trabelsi, we propose to use a-posteriori error estimates to evaluate the error made on the computation of the gradient. This enables us to ensure that at each step, a genuine descent direction is used in the gradient method. Our method has been applied to the minimization of the Kohn-Vogelius functional in the context of electrical impedance tomography. An article is currently in preparation.

6.2.5. A robust stopping rule for EM algorithm with applications to SAXS measurements

Participants: Federico Benvenuto, Houssem Haddar.

The aim of this work was to develop a fully automatic method for the reconstruction of the volume distribution of diluted polydisperse non-interacting nanoparticles with identical shape from Small Angle X-ray Scattering measurements. The described method solves a maximum likelihood problem with a positivity constraint on the solution by means of an Expectation Maximization iterative scheme coupled with an innovative type of regularization. Such a regularization, together with the positivity constraint results in high fidelity quantitative reconstructions of particle volume distributions making the method particularly effective in real applications. The performance of the method on synthetic data in the case of uni- and bi-modal particle volume distributions are shown. Moreover, the reliability of the method is tested when applied to real data provided by a Xenocs device prototype. Finally, the method can be extended to the analysis of the particle distribution for different types of nano-structures.

6.3. Shape and topology optimization

6.3.1. Stacking sequence and shape optimization of laminated composite plates

Participant: Grégoire Allaire.

We consider the optimal design of composite laminates by allowing a variable stacking sequence and in-plane shape of each ply. In order to optimize both variables we rely on a decomposition technique which aggregates the constraints into one unique constraint margin function. Thanks to this approach, a rigorous equivalent bi-level optimization problem is established. This problem is made up of an inner level represented by the combinatorial optimization of the stacking sequence and an outer level represented by the topology and geometry optimization of each ply. We propose for the stacking sequence optimization an outer approximation method which iteratively solves a set of mixed integer linear problems associated to the evaluation of the constraint margin function. For the topology optimization of each ply, we lean on the level set method for the description of the interfaces and the Hadamard method for boundary variations by means of the computation of the shape gradient. An aeronautic test case is exhibited subject to different constraints, namely compliance, reserve factor and first buckling load. This is joint work with G. Delgado.

6.3.2. Thickness control in structural optimization via a level set method

Participant: Grégoire Allaire.

In the context of structural optimization via a level-set method we propose a framework to handle geometric constraints related to a notion of local thickness. The local thickness is calculated using the signed distance function to the shape. We formulate global constraints using integral functionals and compute their shape derivatives. We discuss different strategies and possible approximations to handle the geometric constraints. We implement our approach in two and three space dimensions for a model of linearized elasticity. As can be expected, the resulting optimized shapes are strongly dependent on the initial guesses and on the specific treatment of the constraints since, in particular, some topological changes may be prevented by those constraints. This is a joint work with G. Michailidis

6.4. Asymptotic Analysis

6.4.1. Effective boundary conditions for thin periodic coatings

Participants: Mathieu Chamaillard, Houssem Haddar.

This topic is the object of a collaboration with Patrick Joly and is a continuation of our earlier work on interface conditions done in the framework of the PhD thesis of Berangère Delourme. The goal here is to derive effective conditions that model scattering from thin periodic coatings where the thickness and the periodicity are of the same length but very small compared to the wavelength. The originality of our work, compared to abundant literature is to consider the case of arbitrary geometry (2-D or 3-D) and to consider higher order approximate models. We formally derived third order effective conditions after exhibiting the full asymptotic expansion of the solution in terms of the periodicity length.

6.4.2. Homogenization of the transmission eigenvalue problem with applications to inverse problems

Participant: Houssem Haddar.

In a joint work with F. Cakoni and I. Harris, we consider the interior transmission problem associated with the scattering by an inhomogeneous (possibly anisotropic) highly oscillating peri-odic media. We show that, under appropriate assumptions, the solution of the interior transmission problem converges to the solution of a homogenized problem as the period goes to zero. Furthermore, we prove that the associ-ated real transmission eigenvalues converge to transmission eigenvalues of the homogenized problem. Finally we show how to use the first transmission ei-genvalue of the period media, which is measurable from the scattering data, to obtain information about constant effective material properties of the periodic media. The obtained convergence results are not optimal. Such results with rate of convergence involve the analysis of the boundary correction and will be subject of a forthcoming paper.

6.4.3. Homogenization of electrokinetic models in porous media

Participant: Grégoire Allaire.

With R. Brizzi, J.-F. Dufrêche, A. Mikelic and A. Piatnitski, are interested in the homogenization (or upscaling) of a system of partial differential equations describing the non-ideal transport of a N-component electrolyte in a dilute Newtonian solvent through a rigid porous medium. Our recent work has focused on the so-called non-ideal case. Namely we consider the mean spherical approximation (MSA) model which takes into account finite size ions and screening effects. On the one hand we established a rigorous homogenized transport model starting from this microscopic model. On the other hand we did numerical simulations to ompute the corresponding effective parameters and make systematic comparisons between the idea model and the MSA model.

6.4.4. Modeling and Simulation of the Mechanical behavior of Vesicles and Red Blood Cells

Participant: Olivier Pantz.

6.4.4.1. Highly anisotropic thin shells

With K. Trabelsi (IPSA), we have proposed a new justification of various non linear highly anisotropic elastic shell models. Among others, we do derive the so called Helfrich functional, that describe the behavior of the lipid bilayer of the vesicle and red blood cells. Our results will soon be published in MEMOCS (Mathematics and Mechanics Complex Systems).

6.4.4.2. Minimization of the Helfrich functional

Our work with K. Trabelsi established that the mechanical behavior of vesicles and red blood cells can be approximated by thin non linear anisotropic elastic shells. Minimizing directly the Helfrich functional is not an easy task from the numerical point of view. Most methods require the use of high order finite elements and stabilization techniques so to prevent mesh degeneration. Instead, we propose to approximate the two dimensional membrane of a vesicle (or red blood cell) by a three dimensional non linear elastic body of small thickness. Firstly, this enable us to use standard finite elements and discretization (basically Lagrange of degree 2). Secondly, the discretized formulation is intrinsically stable, so no stabilization is needed. Finally, even if it leads us to solve a three dimensional problem (instead of the two dimensional initial one), it is no more costly than a direct two dimensional approach as the scale of the mesh can be chosen to be of the same order than the "thickness" of the shell. We have already obtained encouraging results for vesicles. We plan to extend them to the case of vesicles with spontaneous curvature and to red blood cells. Moreover, we are considering different strategies to minimize the computational cost (that is already quite satisfying compared with some other methods).

6.4.5. Modeling of Damage and Fracture

Participant: Olivier Pantz.

6.4.5.1. Fracture as limit of Damage

With Leila Azem (PhD Student), we use a model introduced by G. Allaire, F. Jouve and N. Van Goethem in a previous work to simulate the propagation of fracture. The main idea is to approximate the fracture as a damage material and to compute the evolution of the path of the crack using a shape gradient analysis. Our main contribution consists to propose to use a material derivative approach to compute the shape gradient. The advantage is that it drastically simplify the evaluation of the shape gradient, as no regularization is needed and no jump terms as to be computed on the interface bewteen the healthy and damaged areras. An article is currently in preparation to present our results.

6.4.5.2. Fracture with penalization of the jump

With Leila Azem, we propose to approximate a model of fracture with penalization of the jump of the displacement as a limit of a damage model. This is achieved by a specific choice of the softness of the damage material with respect to the cost to turn material from a healthy to a damaged state. We have carried out a formal analysis to justify our approach and have already obtained several numerical results.

6.5. Diffusion MRI

Participants: Jing-Rebecca Li, Houssem Haddar, Simona Schiavi, Khieu Van Nguyen, Gabrielle Fournet, Dang Van Nguyen.

Diffusion Magnetic Resonance Imaging (DMRI) is a promising tool to obtain useful information on microscopic structure and has been extensively applied to biological tissues. In particular, we would like to focus on two applications:

- Inferring from DMRI measurements changes in the cellular volume fraction occurring upon various physiological or pathological conditions. This application is one of the first to show the promise of DMRI because it can detect acute cerebral ischemia (cell swelling) on the basis of lower than normal apparent diffusion coefficient a few minutes after stroke;
- Estimating the average cell size in the case of tumor imaging This application is useful as a diagnostic tool as well as a tool for the evaluation of tumor treatments;

For both of the above applications we approach the problem via the following steps:

- Construct reduced models of the multiple-compartment Bloch-Torrey partial differential equation (PDE) using homogenization methods.
- Invert the resulting reduced models for the biological parameters of interest: the cellular volume fraction in the first case, and the average distance between neighboring cells in the second case.

We obtained the following results.

- We derived using homogenization techniques an asymptotic model of the diffusion MRI signal for finite pulse magnetic field gradient sequences in the long diffusion time regime and numerically verified it using a Finite Element method for both isotropic and anisotropic diffusion configurations in three dimensions. This resulted in 2 publications.
- We derived a new asymptotic model of the diffusion MRI signal for low gradient strengths that is valid for a wide range of diffusion time scales. An article describing our results is under preparation.
- We performed a numerical study of a cylinder model of the diffusion MRI signal for neuronal dendrite trees. This resulted in 1 publication.
- We implemented a compressed sensing method for obtaining T2-weighted images in shorter scanning time and this method was used to segment nerve cells of the Aplysia Californica at the MRI center Neurospin. An article describing our results is under preparation.
- We participated in the characterization of glioma microcirculation and tissue features in a rat brain model using diffusion-encoding magnetic field gradient pulses sequences, working along with collaborators at the high field brain MRI center Neurospin. This resulted in 1 publication.
- We performed Monte-Carlo simulation of blood flow in micro-vessels in the brain with the goal of using the results to explain the MRI signal drop due to incoherent flow in the micro-vessels. This is an ongoing project.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- Contract with EDF R&D on non destructive testing of concrete materials (in the framework of the PhD thesis of Lorenzo Audibert, to be defended in 2015)
- Houssem Haddar has a contract with EDF R&D on data assimilation for temprature estimates in nuclear reactors (in the framework of the PhD thesis of Thibault Mercier, to be defended in 2015)

7.2. Bilateral Grants with Industry

7.2.1. FUI Projects

- Gregoire Allaire is in charge of the RODIN project. RODIN is the acronym of "Robust structural Optimization for Design in INdustry". This is a consortium of various companies and universities which has been sponsored by the FUI AAP 13 for 3 years, starting on July 2012. The industrial partners are: Renault, EADS, ESI, Eurodecision, Alneos, DPS. The academic partners are: CMAP at Ecole Polytechnique, Laboratoire J.-L. Lions at Paris 6 and 7 Universities, centre de recherches Bordeaux Sud-Ouest at Inria. The goal of the RODIN project is to perform research and develop a computer code on geometry and topology optimization of solid structures, based on the level set method.
- Houssem Haddar is in charge of DEFI part of the FUI project Nanolytix. This three years project started in October 2012 and involves Xenocs (coordinator), imXPAD, Arkema, Inria (DEFI) and CEA-Leti. It aims at building a compact and easy-to use device that images nonaparticles using X-ray diffraction at small or wide angles (SAXS and WAXS technologies). We are in charge of direct and inverse simulation of the SAXS and WAXS experiments.
- Houssem Haddar is in charge of the electormagnetic simulation work package of the FUI project Tandem. This three years project started in December 2012 and involves Bull-Amesys (coordinator), BOWEN (ERTE+SART), Ecole Polytechnique (CMAP), Inria, LEAT et VSM. It aims at constructing a radar system on a flying device capable of real-time imaging mines embedded in dry soils (up to 40 cm deep). We are in charge of numerical validation of the inverse simulator.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

- H. Haddar is the DEFI coordinator of the ANR: Modelization and numerical simulation of wave propagation in metamaterials (METAMATH), program MN, 2011-2015. This is a joint ANR with POEMS, Inria Scalay Ile de France project team (Coordinator, S. Fliss), DMIA, Département de Mathématiques de l'ISAE and IMATH, Laboratoire de Mathématiques de l'Université de Toulon. https://www.rocq.inria.fr/poems/metamath
- J.R. Li is the coordinator of the Inria partner of the project "Computational Imaging of the Aging Cerebral Microvasculature", funded by ANR Program "US-French Collaboration". French Partners (Coordinating partner CEA Neurospin): CEA Neurospin (Coordinator Luisa Ciobanu), Inria Saclay (Coordinator Jing-Rebecca Li). US Partner: Univ of Illinois, bioengineering department (Coordinator Brad Sutton). Duration: Sept 2013- Sept 2016.

8.2. European Initiatives

8.2.1. Collaborations with Major European Organizations

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

Joint PhD advising of T. Rienmuller, partly funded by French-German university. Correspondant: Armin Lechleiter.

Partner 2: University of Goettingen, Department of Math. (Germany)

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

Partner 3: 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 International Labs

- H. Haddar is member and the Inria correspondant of EPIC, an Inria team of LIRIMA Afrique.

8.3.2. Inria International Partners

8.3.2.1. Declared Inria International Partners

Title: Qualitative Approaches to Scattering and Imaging (QUASI)

International Partner (Institution - Laboratory - Researcher):

University of Delaware, Department of Mathematical Sciences (USA)

Duration: since 2013

Abstract: We concentrate on the use of qualitative methods in acoustic and electromagnetic inverse scattering theory with applications to nondestructive evaluation of materials and medical imaging. In particular, we would like to address theoretical and numerical reconstruction techniques to solve the inverse scattering problems using either time harmonic or time dependent measurements of the scattered field. The main goal of research in this field is to not only detect but also identify geometric and physical properties of unknown objects in real time.

8.3.3. Participation In other International Programs

- Olivier Pantz is in charge of the french side of the PHC (Hubert Curien Project) *Sur l'étude de quelques problèmes d'équations aux dérivées partielles issus de la physique* (with H. Zorgati of the University of Tunis in charge for the Tunisian side).

8.4. International Research Visitors

8.4.1. Visits of International Scientists

We had short visits (one week) of the following collaborators

- Fioralba Cakoni
- David Colton
- Drossos Gintides
- Ozgur Ozdemir
- Rainer Kress
- Armin Lechleiter
- Nicolas Chaulet

8.4.1.1. Internships

- Shixu Meng
- Jacob Rezac
- Irena de Teresa-Trueba
- Thi Minh Phuong Nguyen
- Afa Saaidi

8.4.1.2. Research stays abroad

- H. Haddar spent one month research visit to the University of Sfax in October 2014.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

- H. Haddar organized a minisymposium on "Inverse Scattering" at IPTA 2014 http://ipta2014.iopconfs.org/218704
- H. Haddar co-organized with Marc Bonnet a minisymposium on "Asymptotic Expansions" at IPTA 2014 http://ipta2014.iopconfs.org/218704
- H. Haddar co-organized with Nicolas Chaulet a minisymposium on "Asymptotics, Inverse Problems and Applications" at SIAM Conference on IMAGING SCIENCE http://www.math.hkbu.edu.hk/SIAM-IS14/Minisymposia.html

9.1.1.1. General chair, scientific chair

- G. Allaire is the scientific chair and one of the five organizers of the conference Conca60-BCAM, Bilbao (december 2014).
- G. Allaire is the scientific chair and one of the main organizers of the CEA/GAMNI seminar on computational fluid mechanics, IHP Paris (January 2014).
- O. Pantz is Co-chairman of the symposium *Optimization tools for large scale industrial systems* for COPI'14, École Polytechnique, (October 2014)

9.1.1.2. Member of the conference program committee

- G. Allaire and H. Haddar are members of the scientific committee of PICOF'2014 http://www.lamsin.tn/picof14/

9.1.2. Journal

9.1.2.1. Member of the editorial board

- G. Allaire is member of the editorial borads of
  - 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,
  - OGST (Oil and Gas Science and Technology),
  - Journal de l'Ecole Polytechnique - Mathématiques.
- H. Haddar is member of the editorial advisory board of Inverse Problems
- J.-R. Li is an Associate Editor of the SIAM Journal on Scientific Computing.

9.1.2.2. Reviewer

The members of the team reviewed numerous papers for numerous international journals. Too many to make a list.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

- Licence : Grégoire Allaire, "Numerical Analysis and Optimization", (main instructor) 27 equivalent TD hours, L3, Ecole Polytechnique, Palaiseau, France
- Licence : Olivier Pantz, "Numerical Analysis and Optimization", 72 equivalent TD hours, L3, Ecole Polytechnique, Palaiseau, France
- Licence : Houssem Haddar, "Numerical Analysis and Optimization", 56 equivalent TD hours, L3, Ecole Polytechnique, Palaiseau, France
- Master : Grégoire Allaire, "Optimal design of structures", (main instructor) 13,5 equivalent TD hours, M1, Ecole Polytechnique, Palaiseau, France
- Master : Grégoire Allaire, "Transport et Diffusion", (main instructor) 6,5 equivalent TD hours, M1, Ecole Polytechnique, Palaiseau, France
- Master : Grégoire Allaire, "Functional analysis and applications", (main instructor) 18 equivalent TD hours, M2, University Pierre et Marie Curie, Paris, France
- Master : Houssem Haddar, "Inverse problems", (main instructor) 24 equivalent TD hours, M2, Ecole Polytechnique, Palaiseau, France
- Master : Olivier Pantz, "Optimal design of structures", 14 equivalent TD hours, M1, Ecole Polytechnique, Palaiseau, France
- Master : Olivier Pantz, "Introduction to calculus of variation ans asymptotic analysis", 40 equivalent TD hours, M1, Ecole Polytechnique, Palaiseau, France
- Doctorat : Houssem Haddar, "Introduction to qualitative methods for inverse electromagnetic scattering theory" at CIME summer school, 12 equivalent TD hours, Cetraro, Italy
- Doctorat : Olivier Pantz, "Introduction course" at the 'FreeFem++ days'. University Pierre et Marie Curie, Paris, France

9.2.2. Supervision

- Ph.D. in progress: L. Audibert, Qualitative methods for non destructive testing of concrete like materials, 2012, H. Haddar
- Ph.D. in progress: T. Mercier, Data assimilation for temperature estimates in PWR, 2012, H. Haddar
- Ph.D. in progress: M. Lakhal, Time domain inverse scattering for buried objects, 2014, H. Haddar
- Ph.D. in progress: T.P. Nguyen, Direct and Inverse scattering from locally perturbed layers, 2013, H. Haddar
- Ph.D. in progress: T. Rienmuller, Scattering for inhomogeneous waveguides, 2014, A. Lechleiter and H. Haddar
- Ph.D. in progress: B. Charfi, Identification of the sigular support of a GIBC, 2014, H. Haddar and S. Chaabane
- Ph.D. in progress: G. Fournet, Inclusion of blood flow in micro-vessels in a new dMRI signal model, 2013, J.-R. Li and L. Ciobanu
- Ph.D. in progress: S. Schiavi, Homogenized models for Diffusion MRI, 2013, H. Haddar and J.-R. Li
- Ph.D. in progress: K. Van Nguyen, Modeling, simulation and experimental verification of water diffusion in neuronal network of the Aplysia ganglia, 2014, J.-R. Li and L. Ciobanu
- PhD in progress : A. Maury, shape optimization for non-linear structures, 2013, G. Allaire and F. Jouve
- PhD in progress : J.-L. Vié, optimization algorithms for topology design of structures, 2013, G. Allaire and E. Cancès

- PhD in progress : C. Patricot, coupling algorithms in neutronic/thermal-hydraulic/mechanics for numerical simulation of nuclear reactors, 2013, G. Allaire and E. Hourcade
- PhD in progress : A. Talpaert, the direct numerical simulation of vapor bubbles at low Mach number with adaptative mesh refinement, 2013, G. Allaire and S. Dellacherie
- PhD in progress : A. Bissuel, linearized Navier Stokes equations for optimization, floating and aeroaccoustic, 2014, G. Allaire
- PhD in progress : M. Giacomini, Shape optimization and Applications to aeronautics, 2013, O. Pantz and K. Trabelsi
- PhD in progress : L. Azem, Modeling and simulation of damage and fracture, O. Pantz and H. Zorgati

9.3. Popularization

- H. Haddar gave a lecture at UnithéouCafé on "Décoder les ondes". The video is available at the youtube inriachannel https://www.youtube.com/watch?v=baS8mL66xiE

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] L. Audibert, H. Haddar. *A generalized formulation of the Linear Sampling Method with exact characterization of targets in terms of farfield measurements*, in "Inverse Problems", 2014, vol. 30, n^{o} 035011 [*DOI :* 10.1088/0266-5611/30/3/035011], https://hal.inria.fr/hal-00911692

[2] Y. Boukari, H. Haddar. *A Convergent Data Completion Algorithm Using Surface Integral Equations*, in "Inverse Problems", 2015, 21 p. , https://hal.inria.fr/hal-01110005

[3] F. Cakoni, H. Haddar, N. Chaulet. *Asymptotic analysis of the transmission eigenvalue problem for a Dirichlet obstacle coated by a thin layer of non-absorbing media*, in "IMA Journal of Applied Mathematics", 2014, 36 p. [*DOI :* 10.1093/IMAMAT/HXU045], https://hal.inria.fr/hal-01109975

[4] N. Chaulet, H. Haddar. *Electromagnetic inverse shape problem for coated obstacles*, in "Advances in Computational Mathematics", September 2014, 21 p. , https://hal.inria.fr/hal-01110003

[5] J. Coatléven, H. Haddar, J.-R. Li. *A macroscopic model including membrane exchange for diffusion MRI*, in "SIAM Journal on Applied Mathematics", 2014, vol. 2, pp. 516-546 [*DOI :* 10.1137/130914255], https://hal.inria.fr/hal-00768732

[6] H. Haddar, Z. Jiang, A. Lechleiter. *Artificial boundary conditions for axisymmetric eddy current probe problems*, in "Computers and Mathematics with Applications", 2015, 23 p. , https://hal.archives-ouvertes.fr/hal-01072091

[7] S. Meng, H. Haddar, F. Cakoni. *The Factorization Method for a Cavity in an Inhomogeneous Medium*, in "Inverse Problems", 2014, vol. 30, n^{o} 045008 [*DOI :* 10.1088/0266-5611/30/4/045008], https://hal.inria.fr/hal-00936557

Research Reports

[8] H. HADDAR, Z. JIANG. *Validity of some asymptotic models for eddy current inspection of highly conducting thin deposits*, July 2014, n^{o} RR-8556, https://hal.inria.fr/hal-01016568

Scientific Popularization

[9] A.-M. BAUDRON, J.-J. LAUTARD, Y. MADAY, M. K. RIAHI, J. SALOMON. *Parareal in time 3D numerical solver for the LWR Benchmark neutron diffusion transient model*, in "Journal of Computational Physics", December 2014, vol. 279, pp. 67 - 79 [*DOI :* 10.1016/J.JCP.2014.08.037], https://hal.archives-ouvertes.fr/hal-00722802

Other Publications

[10] L. AUDIBERT, G. ALEXANDRE, H. HADDAR. *Identifying defects in an unknown background using differential measurements*, 2014, https://hal.inria.fr/hal-01110270

[11] A.-S. BONNET-BEN DHIA, L. CHESNEL, S. NAZAROV. *Non-scattering wavenumbers and far field invisibility for a finite set of incident/scattering directions*, January 2015, https://hal.archives-ouvertes.fr/hal-01109534

[12] L. CHESNEL, X. CLAEYS. *A numerical approach for the Poisson equation in a planar domain with a small inclusion*, October 2014, https://hal.archives-ouvertes.fr/hal-01109552

[13] L. CHESNEL, N. HYVÖNEN, S. STABOULIS. *Construction of invisible conductivity perturbations for the point electrode model in electrical impedance tomography*, December 2014, https://hal.archives-ouvertes.fr/hal-01109544

[14] H. HADDAR, Z. JIANG, M. K. RIAHI. *A robust inversion method for quantitative 3D shape reconstruction from coaxial eddy-current measurements*, 2014, https://hal.inria.fr/hal-01110299

[15] H. HADDAR, M. K. RIAHI. *3D direct and inverse solvers for eddy current testing of deposits in steam generator*, July 2014, 34p, https://hal.inria.fr/hal-01044648

[16] F. OUAKI, G. ALLAIRE, S. DESROZIERS, G. ENCHÉRY. *A Priori Error Estimate of a Multiscale Finite Element Method for Transport Modeling*, 2014, https://hal.archives-ouvertes.fr/hal-01071637