INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team DeFI

Shape Reconstruction and Identification

Saclay - Île-de-France

Theme : COMPUTATIONAL MODELS AND SIMULATION

Activity Report

2009

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DeFI is a joint research group between INRIA Saclay Ile de France and Ecole Polytechnique, hosted by the Centre de Mathématiques Appliquées (CMAP) at Ecole Polytechnique.

1. Team

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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/or shape and topological optimization problems in connection with acoustics, electromagnetism, elastodynamics, and waves in general.

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

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

- 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 precise applications or tutorial toolboxes.

2.2. Highlights

- A. Lechleiter won a second prize at the 14th Leslie Fox Prize Competition in Numerical Analysis at the University of Warwick http://www.warwick.ac.uk/~masdr/fox/.
- Jointly with F. Golse (CMLS, Ecole Polytechnique) G. Allaire launched a new course at the first year Master level at Ecole Polytechnique on "transport and diffusion", in the framework of a new educational program on energy. A set of lecture notes has been written and is available on the course web page: `http://www.cmap.polytechnique.fr/~allaire/cours_map567.html`

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/or shape and topological optimization problems in connection with acoustics, electromagnetism, elastodynamics, and waves in general. We are particularly interested in the development of fast methods that are suited for real-time imaging 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 example of inverse scattering problems (from inhomogeneities), which will be central in most of foreseen developments. 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 partic- ularly 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.

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-tonoise 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.

5. Software

5.1. FreeFem++ Toolboxes

5.1.1. Structural Optimization

Participants: Olivier Pantz, Grégoire Allaire.

This is a toolbox that contains efficient implementations of shape optimization methods in 2-D using the free finite element software `FreeFem++`. It supports boundary variation methods and the homogenization method. A web page of this toolbox is available at http://www.cmap.polytechnique.fr/~allaire/freefem_en.html.

5.1.2. Contact management

Participant: Olivier Pantz.

This toolbox implements the simulation of non-intersection constraints between several deformable bodies. It 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.

5.1.3. ff++2Swf

Participants: Olivier Pantz, Dimitri Nicolas.

We developed a visualization tool that convert Freefem++ outputs into flash movies and that has the advantage of generating small files easy to embed in a web page or in a slide presentation. We intend to include this tool in the Freefem++ distribution, since many Freefem++ users would be interested.

5.2. Scilab and Matlab Toolboxes

5.2.1. Shape optimization

Participant: Grégoire Allaire.

With a student from Caltech, Anton Karrman, who did an internship at CMAP, we developed a Scilab toolbox on shape and topology optimization by the level set method (in 2-d). 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

5.2.2. Conformal mapping method

Participant: Houssem Haddar.

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.

5.2.3. Spectral Method for Lipmann-Schwinger Equation

Participants: Armin Lechleiter, Dinh Liem Nguyen.

This Matlab toolbox solves scattering problems for inhomogeneous media in two and three dimensions using an integral approach. The underlying Lippmann-Schwinger integral equation is discretized using the fast Fourier transform by a spectral method following ideas of Vainikko. The discrete system is then solved by an iterative solver (e.g., GMRES). The toolbox also offers the possibility to precondition the solver by a two-grid approach.

5.3. Samplings-2D

Participant: Houssem Haddar.

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. A web page of this software is available at http://www.cmap.polytechnique.fr/~haddar/.

5.4. Lsm&Rglsm-3D

Participant: Houssem Haddar.

These Fortran 90 codes are dedicated to the solution of the 3-D electromagnetic inverse scattering problem using RGLSM or LSM. There are parallel versions of these codes that are coupled to the CESC code (solver for electromagnetic scattering problems using integral equation methods) developed at CERFACS by M'Barek Fares. They also support imaging for doubly layered medium.

6. New Results

6.1. Sampling methods for inverse scattering problems

6.1.1. Factorization Method for Periodic Penetrable Media

Participant: Armin Lechleiter.

Imaging periodic penetrable scattering objects is of interest for non-destructive testing of photonic devices. The problem is motivated from the decreasing size of periodic structures in photonic devices, together with an increasing demand in fast non-destructive testing. In this project, we consider the problem of imaging a periodic penetrable structure from measurements of scattered electromagnetic waves. Qualitative inverse scattering techniques are particularly attractive here since they do not use time consuming optimization techniques for reconstruction but rather directly transform measured data into a picture of the scattering object. We show that the Factorization method can be used as an algorithm for imaging of a special class of periodic dielectric structures known as diffraction gratings. Our sampling method computes a picture of the shape of the periodic structure from measured near-field data in a rapid way [38].

6.1.2. Noise Subspace Methods for Inverse Scattering Problems

Participant: Armin Lechleiter.

The MUSIC algorithm is a well-known imaging technique in signal processing for determining the location of emitters from sensors with arbitrary locations and directional characteristics in a noisy environment. Recent research in the inverse scattering literature has sought to apply this technique to determine not only the location, but the shape of extended scatterers. In a joint work with Tilo Arens and D. Russell Luke we relate the MUSIC algorithm to the Factorization method and show that MUSIC is actually applicable to inverse scattering problems without constraint on the object size. These results are also extended to scattering from cracks. With explicit constructions in hand, we are also able to provide error and stability estimates for practical implementations in noisy environments with limited data. In particular, we address the relation of the spectral properties of the continuous far field operator to those of the discrete version used implicitly in numerical examples appearing in the literature [8].

6.1.3. The RG-LSM method applied to urban infrastructure imaging

Participant: Houssem Haddar.

The RG-LSM algorithm has been introduced by Colton-Haddar in 2005 as a reformulation of the linear sampling method in the cases where measurements consist of Cauchy data at a given surface, by using the concept of reciprocity gap. The main advantage of this algorithm is to avoid the need of computing the background Green tensor (as required by classical sampling methods) as well as the Dirichlet-to-Neumann map for the probed medium (as required by sampling methods for impedance tomography problems). This method is for instance well suited for medical imaging techniques using microwaves (to detect tumors and malignancies characterized by strong variation in dielectric properties). However, in many other practical applications, like imaging of embedded facilities in the soil or mine detection, the required data at the interface cannot be easily obtained and one has only access to measurements of the scattered wave in the air. In order to overcome this limitation we proposed to couple the RG-LSM algorithm with a continuation method that would provide the Cauchy data from the scattered field. We showed that the obtained scheme has the same convergence properties as RG-LSM with exact data and remains competitive with respect to classical approaches. Preliminary numerical results in a 2-D configuration confirmed these conclusions and also gave further insight on the sampling resolution: Due to the ill-posedness of the first step, only the propagative part of the wave is well reconstructed, which may results in poor approximations of the field. However, the second step (RG-LSM) seems not being affected by this error and therefore is the reconstruction of the target. In a joint work with O. Ozdemir we first extended this approach to the case of rough interfaces [37]. Motivated by microwave imaging experiments, we are currently investigating the cases where the inclusions are buried under thin rough layers for which the use of generalized interface conditions would be appropriate. A long time prospective of this work is to tackle the 3-D electromagnetic case.

6.1.4. Inverse scattering from screens with impedance boundary conditions

Participants: Houssem Haddar, Yosra Boukari.

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 in a first step the use of the linear sampling method and the reciprocity-gap sampling method to retrieve the shape of the screen and we are currently analyzing the accuracy of these methods with respect to the impedances values as well as using this analysis to derive a priori estimates on the impedances values. This work is pursued in collaboration with F. Ben Hassen.

6.1.5. Sampling methods with time dependent data

Participants: Houssem Haddar, Armin Lechleiter.

In collaboration with P. Monk and Q. Chen from the University of Delaware, we extended the use of sampling methods to inverse scattering problems with time dependent data. We considered in this first investigation the scalar problem and obstacles with Dirichlet boundary conditions. Motivated by ground penetrating radar experiments, we treated the case of near field scattered data generated by incident point sources with causal pulses. We first formulate the sampling algorithm using appropriate convolution in time. The causality assumption introduces additional difficulty is carrying out usual theoretical analysis of the method since one cannot rely on the use of Fourier transform. We provide a factorization of the sampling operator using retarded potentials which are then analyzed with the help of a Fourier-Laplace analysis. We also performed preliminary numerical simulations where the sampling equation is solved using truncated singular value decomposition. The obtained numerical results show good reconstructions and provide a satisfactory validation of our approach.

6.1.6. Transmission Eigenvalues and their application to the identification problem

Participants: Anne Cossonnière, Houssem Haddar.

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. Three contributions have been accomplished:

- *On the Determination of Dirichlet or Transmission Eigenvalues from Far Field Data.* In this joint work with F. Cakoni and D. Colton we show that the Herglotz wave function with kernel the Tikhonov regularized solution of the far field equation becomes unbounded as the regularization parameter tends to zero iff the wavenumber k belongs to a discrete set of values. When the scatterer is such that the total field vanishes on the boundary, these values correspond to the square root of Dirichlet eigenvalues for $-\Delta$. When the scatterer is a non absorbing inhomogeneous medium these values correspond to so-called transmission eigenvalues. This work provides for instance a theoretical justification of the algorithm that localises the transmission eigenvalues based on the behavior of the solution to the far field equation with respect to the frequency [33].
- *The Interior Transmission Problem For regions with Cavities.* In this joint work with F. Cakoni and D. Colton we considered the interior transmission problem in the case when the inhomogeneous medium has cavities, i.e. regions in which the index of refraction is the same as the host medium. In this case we establish the Fredholm property for this problem and show that transmission eigenvalues exist and form a discrete set. We also derive Faber-Krahn type inequalities for the transmission eigenvalues [12].

- *The existence of an infinite discrete set of transmission eigenvalues*. This problem was open for a long time. Jointly with F. Cakoni, D. Gintides we prove the existence of an infinite discrete set of transmission eigenvalues corresponding to the scattering problem for isotropic as well as anisotropic inhomogeneous media for the Helmholtz and Maxwell's equations. Our discussion also includes the case of the interior transmission problem for an inhomogeneous medium with cavities, i.e. subregions with contrast zero [13].

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, theoretcial results related to solutions of the interior transmission problem for medium with cavities and existence of transmission eigenvalues have been obtained. During September-December 2009, A. Cossonnière visited the UDEL and studied the continuity of transmission eigenvalues with respect to the medium properties. Parallel to this work, G. Giorgi, who started in 2009 a PhD thesis co-directed by H. Haddar and M. Piana begun investigating (during a three months training at the DEFI team) a new procedure to improve the lower bound on medium index from observed transmission eigenvalue based on ideas inspired by the work of Cakoni-Gintides-Haddar mentioned above.

6.2. Iterative Methods for Non-linear Inverse Problems

6.2.1. Convergence Analysis of Newton type methods

Participant: Armin Lechleiter.

Despite Newton-like methods are among the classical techniques for solving non-linear inverse problems, their convergence analysis is still incomplete. In a joint project with Andreas Rieder, we develop a general convergence analysis for an entire class of inexact Newton-type regularizations for stably solving nonlinear ill-posed problems. The methods under consideration consists of two components: the outer Newton iteration (stopped by a discrepancy principle) and an inner regularization scheme which provides the update of the iteration. In this paper we give a novel and unified convergence analysis which is not restricted to a specific inner regularization scheme. Indeed, our analysis applies to a variety of schemes including Landweber and steepest decent iterations, iterated Tikhonov method, and method of conjugate gradients [19].

6.2.2. Hybrid methods for inverse scattering problems

Participants: Grégoire Allaire, Houssem Haddar, Olivier Pantz, 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.

Dimitri Nicolas started his PhD on September 2009 on this topic under the supervision of G. Allaire. Preliminary 2-d numerical experiments have been conducted by initializing a geometric optimization algorithm with the shape provided by the linear sampling method. The obtained results validate the efficiency of this coupling in the case of simply connected obstacles. More complex configurations are under investigations.

6.2.3. The conformal mapping method for the inverse conductivity problem

Participant: Houssem Haddar.

In a series of recent papers Akduman, Haddar and Kress have developed a new simple and fast numerical scheme for solving two-dimensional inverse boundary value problems for the Laplace equation that model non-destructive testing and evaluation via electrostatic imaging. In the fashion of a decomposition method, the reconstruction of the boundary shape Γ_0 of a perfectly conducting or a nonconducting inclusion within a doubly connected conducting medium $D \subset \mathbb{R}^2$ from over-determined Cauchy data on the accessible exterior boundary Γ_1 is separated into a nonlinear well-posed problem and a linear ill-posed problem. The approach is based on a conformal map $\Psi : B \to D$ that takes an annulus B bounded by two concentric circles onto D. In the first step, in terms of the given Cauchy data on Γ_1, by successive approximations one has to solve a nonlocal and nonlinear ordinary differential equation for the boundary values $\Psi|_{C_1}$ of this mapping on the exterior boundary circle of B. Then in the second step a Cauchy problem for the holomorphic function Ψ in B has to be solved via a regularized Laurent expansion to obtain the unknown boundary $\Gamma_0 = \Psi(C_0)$ as the image of the interior boundary circle C_0.

In a joint work with R. Kress we proposed an extension of this approach to two-dimensional inverse electrical impedance tomography with piecewise constant conductivities. A main ingredient of our method is the incorporation of the transmission condition on the unknown interior boundary via a nonlocal boundary condition in terms of an integral equation. We present the foundations of the method, a local convergence result and exhibit the feasibility of the method via numerical examples [35].

6.3. Shape and topological optimization methods

6.3.1. A two phase optimal design problem for the wave equation

Participant: Grégoire Allaire.

With Alex Kelly, presently a post-doc at CMAP, we are studying a two phase optimal design problem where the state equation is a wave equation. As usual this type of problem is ill-posed, namely it does not admit a solution. Establishing its relaxed formulation is a difficult task, so we simplify the problem by making an assumption on the small amplitude of the contrast. We then perform a second-order asymptotic expansion of the original problem with respect to this small aspect ratio. It is still not a well-posed problem but its relaxation is much more simple, using the notion of H-measures, which is easier to manipulate than homogenization theory. This yields a satisfying existence theory as well as an efficient numerical method for computing the optimal designs. We are currently writing a paper on the topic.

6.3.2. Post-treatment of the homogenization method

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 a joint work with K. Trabelsi) 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. We intend to extend this approach to the minimization of other cost functions and are currently working on the multiload case.

6.3.3. Numerical simulation of damage evolution

Participant: Grégoire Allaire.

With F. Jouve et N. Van Goethem we worked on the numerical implementation of the Francfort-Marigo model of damage evolution in brittle materials. This quasi-static model is based, at each time step, on the minimization of a total energy which is the sum of an elastic energy and a Griffith energy release rate. Such a minimization is carried over all geometric mixtures of the two, healthy and damaged, elastic phases, respecting an irreversibility constraint. Numerically, we consider a situation where two well separated phases coexist, and model their interface by a level set function that is transported according to the shape derivative of the minimized total energy. In the context of interface variations (Hadamard method) and using a steepest descent algorithm, we compute local minimizers of this quasi-static damage model. Initially, the damaged zone is nucleated by using the so-called topological derivative. We show that, when the damaged phase is very weak, our numerical method is able to predict crack propagation, including kinking and branching. Several numerical examples in $2d$ and $3d$ are discussed in [23] and a full article will soon appear.

6.4. Asymptotic models

6.4.1. Long time asymptotic models for the wave equation in periodic media

Participant: Grégoire Allaire.

In a joint work with M. Palombaro and J. Rauch, we studied the homogenization and singular perturbation of the wave equation in a periodic media for long times of the order of the inverse of the period ε. We consider initial data that are Bloch wave packets, i.e., that are the product of a fast oscillating Bloch wave and of a smooth envelope function. We prove that the solution is approximately equal to two waves propagating in opposite directions at a high group velocity with envelope functions which obey a Schrödinger type equation. Our analysis extends the usual WKB approximation by adding a dispersive, or diffractive, effect due to the non uniformity of the group velocity which yields the dispersion tensor of the homogenized Schrödinger equation [6], [32].

Jointly with L. Friz, we extended these previous results in the case of a locally periodic media. In such a case, on top of homogenization appears another effect, called localization (similar to the so-called Anderson localization for the Schrödinger equation in quantum mechanics). We consider initial data that are localized Bloch wave packets, i.e., that are the product of a fast oscillating Bloch wave at a given frequency ξ and of a smooth envelope function whose support is concentrated at a point x with length scale $\sqrt{\varepsilon}$. We assume that (ξ, x) is a stationary point in the phase space of the Hamiltonian $\lambda(\xi, x)$, i.e., of the corresponding Bloch eigenvalue. Upon rescaling at size $\sqrt{\varepsilon}$ we prove that the solution of the wave equation is approximately the sum of two terms with opposite phases which are the product of the oscillating Bloch wave and of two limit envelope functions which are the solution of two Schrödinger type equations with quadratic potential. Furthermore, if the full Hessian of the Hamiltonian $\lambda(\xi, x)$ is positive definite, then localization takes place in the sense that the spectrum of each homogenized Schrödinger equation is made of a countable sequence of finite multiplicity eigenvalues with exponentially decaying eigenfunctions [4].

6.4.2. Interface conditions for thin dielectrics

Participant: Houssem Haddar.

In a first work, in collaboration with S. Chun and J. Hesthaven from Brown University, we established transmission conditions modelling thin anisotropic media in time dependent electromagnetic diffraction problems. The derived interface conditions turn out to be well suited for Discontinuous Galerkin methods since the latter implicitly support discontinuities between elements. The interface conditions only results into a modification of the numerical flux used in DG methods. These conditions has been successfully tested in the 1-D case up the fourth order where stabilization in time has been applied to the fourth order condition. It is also worth noticing that the expression of these conditions in the anisotropic case cannot be simply deduced from the isotropic one by just replacing constant coefficients with their matrix equivalent. We extended the 1-D case to the 2-D and 3-D ones, where stable conditions are designed for curved geometries up tor order 3 and for flat ones up to order 4. These conditions are numerically validated in the 2-D case [34].

Jointly with B. Delourme and P. Joly we are investigating the extension of this work to the cases where the thin interface has (periodic) rapid variations along tangential coordinates. Motivated by non destructive testing experiments of tires, 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. The case of 3-D Maxwell's equations is under study.

6.4.3. Generalized Impedance Boundary Conditions: the forward problem

Participants: Houssem Haddar, Armin Lechleiter.

We studied so-called Generalized Impedance Boundary Conditions (GIBC) in the context of time-harmonic rough surface and rough layer scattering. In such problems one considers scattering objects like an unbounded hypersurface or an inhomogeneous infinitely extended layer. For a variety of interface and boundary conditions including the GBICs, we showed existence and uniqueness of solution for scattering of acoustic or TE/TM polarized electromagnetic waves from such structures. This result is achieved by Rellich identities yielding explicit a-priori bounds on the solution - those also allow to transfer the asymptotic analysis of GBICs for bounded obstacles to the rough surface setting [36]. Currently under investigation is whether these results can be extended to the full electromagnetic rough layer scattering problem.

In collaboration with B. Aslanyurek, who was visiting our group for 9 months in 2009, we derived Generalized Impedance Boundary Conditions that model thin dielectric coatings with variable width. We treated the 2-D electromagnetic problem for both TM and TE polarizations. The expressions of the GIBCs are derived up to the third order (with respect to the coating width). The order of convergence is numerically validated through various numerical examples. A particular attention is given to the cases where the inner boundary has corner singularities [29].

6.4.4. Generalized Impedance Boundary Conditions: the inverse problem

Participants: Houssem Haddar, Nicolas Chaulet.

We are interested here in the identification of a medium impedance from the knowledge of far measurements of a scattered wave at a given frequency. Assuming that the unknown medium occupies a domain D, the medium impedance is understood as a "local" operator that links the Cauchy data of the field u on the medium boundary $\Gamma := \partial D$. More precisely we consider the cases where a boundary condition of the form: $\partial u/\partial\nu + Zu = 0$ on Γ is satisfied, where Z is a boundary operator and ν denotes the outward normal field on Γ.

The exact impedance operator Z corresponds to the so-called Dirichlet-to-Neumann (DtN) map, i.e. $f \mapsto -\partial u/\partial\nu|_\Gamma$ where u solves the Hemholtz equation inside D and satisfies $u = f$ on Γ. Consequently determining this map is "equivalent" to identify the physical properties inside D, which is in general a severely ill-posed problem that requires more than a finite number of measurements.

We are interested here in situations where the operator Z is an approximation of the exact DtN map. In general these approximations correspond to asymptotic models associated with configurations that involve a small parameter. These cases include small amplitude roughness, thin coatings, periodic gratings, highly absorbing media, ...

The simplest form is the case where Z is a scalar function, which corresponds in general to the lowest order (non trivial) approximations, for instance in the case of very rough surfaces of highly absorbing media (the Leontovich condition). However, for higher order approximations or in other cases the operator Z may involve boundary differential operators. For instance when the medium contains a perfect conductor coated with a thin layer of width δ then for TM polarization, the approximate boundary conditions of order 1 corresponds to $Z = 1/\delta$ while for the TE polarization it corresponds to $Z = \delta(\partial_{ss} + k^2 n)$ where s denotes the curvilinear abscissa, k the wave number and n is the mean value of the thin coating index with respect to the normal coordinate. Higher order approximations would include curvature terms or even higher order derivatives. This type of conditions will be referred to as Generalized Impedance Boundary Conditions GIBC. One easily sees, from the given example, how the identification of the impedance would provide information on some effective properties of the medium (for instance, the thickness of the coating and the normal mean value of its index). Determining these effective properties would be less demanding in terms of measurements than solving the inverse problem with the exact DtN map (the unknown parameters have one dimension less) and we also expect that the inherent ill-posedness to be less severe.

In a first work with L. Bourgeois and motivated by the example above we addressed the question of unique identification and stability of the reconstruction of $Z = \mu\Delta_\Gamma + \lambda$ from the knowledge of one scattered wave. After pointing out that uniqueness does not hold in the general case, we propose some additional assumptions for which uniqueness can be restored. We also considered the question of stability when uniqueness holds. We prove in particular Lipschitz stability when the impedance parameters belong to a compact set. We also extend local stability results to the case of back-scattering data [10].

The general goal of the PhD thesis of Nicolas Chaulet (started in October 2009) is to extend this work to more complex expressions of the impedance operator and validate theoretical results through numerical experiments. Some 2-D numerical results are obtained in this direction as well as stability results with respect to error on the boundary location. We also would like to investigate the problem where the boundary is also unknown and analyze whether a GIBC induces cloaking.

6.5. Scattering in Complex Media

6.5.1. The Electromagnetic Lippmann-Schwinger Equations

Participant: Armin Lechleiter.

The Lippmann-Schwinger integral equation describes scattering electromagnetic waves from penetrable objects. If the modeling of the inhomogeneous medium involves space dependent coefficients in the highest order terms of the underlying partial differential equation, then the corresponding integral operators typically fail to be compact. In a joint work with Andreas Kirsch we investigate such cases and study the arising integral equations in weighted spaces of square integrable functions. The two examples we treat are acoustic scattering from a medium with a space dependent material density and electromagnetic medium scattering where both the electric permittivity and the magnetic permeability vary. In these cases, Riesz theory is not applicable for the solution of the arising integral equations of Lippmann-Schwinger type. Therefore we show that positivity assumptions on the relative material parameters allow to prove positivity of the arising volume potentials in tailor-made weighted spaces of square integrable functions. This result merely holds for imaginary wavenumber and we exploit a compactness argument to conclude that the arising integral equations are of Fredholm type, even if the integral operators themselves are not compact. Finally, we explain how the solution of the integral equations in L^2 affects the notion of a solution of the scattering problem and illustrate why the order of convergence of a Galerkin scheme set up in L^2 does not suffer from our L^2 setting, compared to schemes in higher order Sobolev spaces [17].

6.5.2. Spectral Methods for the Lippmann-Schwinger Equation

Participants: Armin Lechleiter, Dinh Liem Nguyen.

Waves in inhomogeneous media with variable refractive index can be described by the Lippmann-Schwinger integral equation. We investigate spectral methods for these integral equations that go back to an idea of Vainikko. In our analysis, we are especially interested in media with non-smooth physical characteristics and analyze the convergence order of adapted numerical schemes for this problem. We are also interested in special ways of discretizing the corresponding integral equations for multiple distant scattering objects. In the future, we aim to apply such spectral techniques to electromagnetic scattering problems in optics.

6.5.3. Scattering from Rough Unbounded Penetrable Layers

Participants: Houssem Haddar, Armin Lechleiter.

Scattering of electromagnetic waves from the surface of ground are often modelled by a time-harmonic scattering problem involving unbounded scattering objects. We are interested in theoretical and numerical studies of this type of problems via variational formulations.

In a first work, A. Lechleiter and S. Ritterbusch considered the scalar problem in dimension two and three. The refractive index describing physical properties of the medium can be real or (partially) complex valued and is allowed to jump across interfaces. However, the index needs to satisfy a non-trapping condition, which requires, roughly speaking, monotonicity in the direction normal to the layer. In the half space above and below the rough layer a radiation condition is set up using the angular spectrum representation. Due to the unbounded setting, integral formulas similar to Rellich's identity are derived to obtain a priori bounds for a variational solution of the rough layer scattering problem. This a-priori bound is the basis for formulated existence result. Regularity theory and bounds on its frequency dependence are also provided [20].

We are also investigating extensions of such approach to the more complicated 3-D electromagnetic problem. In that perspective we considered the scattering of time-harmonic electromagnetic waves from a metallic plate coated with a dielectric layer. This problem occurs for instance when monochromatic light propagates through photonic assemblies mounted on a plate. We first established a variational framework using the DtN map for Maxwell equation in half space. As opposed to the scalar case, the real part of this operator does not have a fix sign, which induces difficulties is establishing existence of solutions. The latter is done using an appropriate limiting absorption principle combined with a priori estimates derived from Rellich type identities. Our analysis only apply to small perturbation of stratified parallel layers. We are now interested in cases where the perfect conductor has a rough surface and also in widening the range of admissible material configurations.

6.6. Blood flow simulation

6.6.1. Simulation of Contacts without friction

Participant: Olivier Pantz.

We have developed a new contact algorithm for bodies undergoing finite deformations. Only the kinematic aspect of the contact problem has been investigated, that is the numerical treatment of the non-intersection constraint. In consequence, mechanical aspects like friction, adhesion or wear have not been considered and we restricted our analysis to the simplest frictionless case. On the other hand, our method allowed us to treat contacts and self-contacts, thin or non-thin structures in a single setting. This work has lead to the publications of two papers. One focus on the simulation of aortic valves, where complex self-contacts between the valves could occur [9]. A c++ code has been developed to treat those contacts and has been coupled with a fluid structure code by the REO team of the INRIA. The other is less specialized to a particular application and give a presentation of the algorithm in a more general setting [30]. It also contains several applications in a two dimensional case (dynamic of balloons, contacts and self-contacts between linear and non-linear elastic bodies). The codes where developed under Freefem++ and C++.

6.6.2. Red Blood Cells Simulation

Participant: Olivier Pantz.

Blood is essentially composed of red blood cells, white blood cells and platelets suspended in a fluid (blood plasma). If it can be considered as a homogeneous fluid when circulating in vessels of large diameter, this approximation is no longer valid when it reaches vessels with diameter of an order of magnitude comparable to that of the cells it carries. In this case, the influence of the cells on the flow can no longer be homogenized. Therefore, the mechanical behavior of red blood cells (which account for 99% of the cells presenting in the blood), their interaction with the surrounding fluid or between themselves (by contact) must be taken into account. Numerical tool plays thus an essential role: it enables to validate the advanced physical models, to access to data difficult to obtain experimentally and to determine the dependence of the flow behavior on the parameters of the model. In [25], we proposed a numerical method which allows to take into account these three essential aspects (mechanical behavior of red blood cells, fluid/structures interactions and structures/structures contact interactions). Our study is limited to the two-dimensional case which, although simplistic, allows us to reproduce a quite large range of experimental observations as shown in the numerical simulations obtained. We intend to extend our analysis to the three dimensional case, which is a lot more difficult to tackle. In particular, both flexural and membrane effects are present in the 3d setting (whereas only flexural effects are relevant in the 2D case). Moreover, the eventual management of the meshes of the RBC and of their interaction with the fluid is also challenging.

6.7. Modelling and simulation for underground nuclear waste storage

Participant: Grégoire Allaire.

Since its foundation in 2002 G. Allaire is a member of the GDR MOMAS (Groupement de Recherches du CNRS sur les MOdélisations MAthématiques et Simulations numériques liées aux problèmes de gestion des déchets nucléaires). The problem of nuclear waste storage is of paramount importance from the industrial, as well as environmental, points of view. In the framework of this GDR MOMAS we are working on three different topics: inverse problems (reconstructing porosity and permeability fields from measurements), multi-scale numerical methods, upscaling by homogenization (finding macroscopic models and effective coefficients).

Jointly with R. Brizzi, A. Mikelic et A. Piatnitski we studied reactive flows through porous media. We supposed dominant Peclet's number, dominant Damköhler's number and general linear reactions at the pore boundaries. Our goal was to obtain the dispersion tensor and the upscaled model. We introduce the *multiple scale expansions with drift* for the problem and use this technique to upscale the reactive flow equations. Our result was illustrated with numerical simulations for the dispersion tensor [5], [2].

7. Contracts and Grants with Industry

7.1. DGA

7.1.1. September 2008 - Agust 2009

Participants: Houssem Haddar, Armin Lechleiter.

This grant is managed by ENSTA and provided financial support to the Post-Doc of Dr. Lechleiter (September 2008 - Aout 2009) on imaging of facilities buried under rough surfaces.

7.1.2. October 2009 - September 2012

Participants: Houssem Haddar, Nicolas Chaulet.

This grant is managed by INRIA and provides financial support to the PhD thesis of Nicolas Chaulet (October 2009-September 2012) on identification/invisibility of coatings in radar applications.

7.2. EADS Foundation

7.2.1. October 2008 - September 2011

Participants: Anne Cossonnière, Houssem Haddar.

This grant is manged by CERFACS and provides financial support to the PhD thesis of Anne Cossonnière on the use on transmission eigenvalues in the identification problem.

7.3. Forthcoming contracts

7.3.1. EDF R&D

Participants: Houssem Haddar, Armin Lechleiter.

We initiated collaboration with the group SDTI (EDF-R&D, Chatou) on non destructive testing of magnetic deposits on PWR fuel rods. A prospected grant in 2010 would provide financial support for a 6 months Master M2 training following by a PhD thesis.

7.3.2. Renault

Participant: Grégoire Allaire.

We initiated collaboration with Renault (Technocentre de Guyancourt) on the development of 3-D structural shape and topological optimisation software. A prospected grant in 2010 would provide financial support for two Master M2 trainings followed by two PhD thesis.

8. Other Grants and Activities

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, the ANR MICA (Mouvements d'Interfaces, Calcul et Applications), and the ANR FF2a3 (3-D version of FreeFem++). He is also managing two scientific contracts with Dassault Aviation and EADS.

8.2. International Initiatives

- Associated team Inverse Scattering and Identification Problems (ISIP) between the mathematical Department of the University of Delaware and the DEFI team has been created January 2008 and renewed for 2010 http://www.cmap.polytechnique.fr/~defi/Prolong-EA-ISIP-10.html. This team is lead by H. Haddar (DeFI) and F. Cakoni (UDEL).
- Stic project DGRST(Tunisie)/INRIA *Méthodes innovantes en imagerie et en contrôle non destructif des structures* lead by H. Haddar DeFI and F. Ben Hassen LAMSIN (2007-2009). This project provided financial Support PhD students R. Mdimagh and Y. Boukari.
- Since 2009, H. Haddar with O. Ozdemir from the electromagnetics research group of ITU (Turkey) have obtained financial support up to 14000 euros from the Turkish National Science Foundation (TUBITAK) for their proposal on "The use of generalized impedance boundary conditions for buried objects imaging and for coatings non destructive testing". The money serves for PhD students and scientific short visits.

8.3. Exterior research visitors

- B.Aslanyurek, PhD student from Yildiz University (Turkey). He spent 9 months (Feb.-Oct 2009) at the DeFI group and was financially supported from TUBITAK.
- O. Ozdemir, Associate Professor from ITU: January 2009 and June-July 2009.
- F. Cakoni, Professor from the University of Delaware: March 29 to April 4, 2009 and June 14-19 2009.
- D. Colton, Professor from the University of Delaware: March 29 to April 4, 2009.
- R. Griesmair, PostDoc from the University of Delaware: April 19-25, 2009.
- R. Kress, Professor from the university of Goettingen: 19-24 May 2009.
- M.A. Bey, PhD from LAMSIN, ENIT: May 2009.
- Q. Chen, PhD from the University of Delaware: June 1-24 2009.
- G. Giorgi, PhD from the University of Genova: October 1 - December 16, 2009.
- F. Ben Hassen from LAMSIN, ENIT: December 16 to December 23, 2009.

9. Dissemination

9.1. Scientific Community Animation

- G. Allaire is co-organiser (since 1991) of the yearly seminar CEA/GAMNI "Mécanique des fluides numériques" (January 2 days),
  is member of the scientific committee of the 8th World Congress on Structural and Multidisciplinary Optimization, Lisboa 2009,
  is member of the organizing committee of SMAI 2009 (La Colle sur Loup, Mai 2009) and MOMAS workshop (Luminy, Movember 2009).
- H. Haddar is member of the scientific committee of the TamTam conference (Kenitra 2009).
- A. Lechleiter is responsible of the workgroup seminar of DeFI.

9.2. Collective Responsabilities

- G. Allaire is co-editor in chief of the collection "Mathématiques et Applications" of SMAI edited by Springer. Member of the editorial committee of the journals ESAIM/COCV since 2000, SIAM Multiscale Modeling and Simulation since 2002, Structural and Multidisciplinary Optimization since 2002, Discrete and Continuous Dynamical Systems Series B since 2003, Computational and Applied Mathematics since 2006, Mathematical Models and Methods in Applied Sciences (M3AS) since 2006, Annali dell'Universita di Ferrara since 2008.
- G. Allaire is President of the applied math. department of Ecole Polytechnique since 2006.
  Member of the administrative committee of SMAI (Société de Mathématiques Appliquées et Industrielles) since 2005.
  Member of the link committee GAMNI/SMAI (Groupement pour l'Avancement des Méthodes Numériques pour l'Ingénieur).
  President of the scientific committee of GDR MOMAS (MOdélisations MAthématiques et Simulations numériques liées aux problèmes de gestion des déchets nucléaires).
  Member of the scientific committee of "Stockage géologique des déchets" de l'IRSN (Institut de Radioprotection et de Sûreté Nucléaire) since 2008.
- H. Haddar is member of the scientific committee of the CMAP.

9.3. Teaching

G. Allaire

- Course "Analyse Numérique et d'Optimisation", for students (~ 250) in the second year of Ecole Polytechnique curriculum.
  http://www.cmap.polytechnique.fr/~allaire/cours_X_annee2.html
- Course "Conception optimale des structures", for students (~ 30) in the third year of Ecole Polytechnique curriculum.
  http://www.cmap.polytechnique.fr/~allaire/cours_X_majeure.html
- Course "Transport et Diffusion" with F. Golse in the framework of the program Energy at Ecole Polytechnique.
  http://www.cmap.polytechnique.fr/~allaire/cours_map567.html
- Course "Analyse théorique et numérique des systèmes hyperboliques de lois de conservation" with F. Coquel for students in Master M2 of Ecole Polytechnique and University of Paris 6.
  http://www.cmap.polytechnique.fr/~allaire/cours_master.html

H. Haddar

- Course “Problèmes directs et inverses en diffraction” with P. Joly for students in Master M2 of Ecole Polytechnique and University of Paris 6.
- Working groups of the course “Analyse Numérique et d’Optimisation”, for students (2 groups of $\sim$20) in the second year of Ecole Polytechnique curriculum.

O. Pantz

- Working groups of the course “Analyse Numérique et d’Optimisation”, for students (2 groups of $\sim$20) in the second year of Ecole Polytechnique curriculum.
- Working groups of the course “Conception optimale des structures”, for students ($\sim$ 30) in the third year of Ecole Polytechnique curriculum.
- Monitor of two projects (6 months) in Numerical Analysis for two groups of 3 students each (second year of Ecole Polytechnique curriculum).

9.4. Seminars, Conferences, Visits

G. Allaire

- 8th World Congress on Structural and Multidisciplinary Optimization, Lisboa (June 2009) - Invited speaker.
- Lecturer at the summer school organized at Université du littoral, Calais (September 2009).
- Invited speaker at the 40th anniversary of the Jacques-Louis Lions laboratory, Paris (December 2009)
- Short course on optimal design delivered at the Ecole Normale d’Alger (November 2009).
- Organization of two events related to MMSN Chair:
  - Topology Optimization WORKSHOP - 6 April 2009
  - "Journée de Bilan de la Chaire MMSN" - 29 September, 2009

A. Cossonnière

- Attended the IMA PI Summer Program for Graduate Students: The Mathematics of Inverse Problems, organized at the university of Delaware, June 15-July 3, 2009 http://www.ima.umn.edu/2008-2009/PISG6.15-7.3.09/.
- Research visit to the math. dept. of the university of Delaware : September-December 2009 sponsored by associate team ISIP.

H. Haddar

- TamTam’09 conference, Kenitra, Morroco, May 2009 - Invited speaker
- Waves 2009 conference, Pau, France - Invited speaker
- Co-Organization of a minisymposium on ”The determination of boundary coefficients in inverse boundary value problems and scattering theory” at AIP conference, Vienna, Austria, July 2009.
- Invited for one weak research visit at LAMSIN, July 2009.

A. Lechleiter

- Talk in the seminar on PDE at Institut Elie Cartan, Université de Nancy, March 2009.
- Workgroup on Inverse Problems at the Department of Mathematics, Karlsruhe, Germany, April 2009 - Invited talk.
- SMAI 2009 conference, La Colle sur Loup, France, Mai 2009 - Contributed talk.

- WAVES 2009 conference, Pau, France, June 2009 - Contributed talk.
- The 2009 Leslie Fox Prize Competition, Warwick, UK, June 2009 - Invited talk
- Minisymposium *Application-oriented sampling methods for inverse scattering problems* at the conference “Applied Inverse Problems”, Vienna, Austria, July 2009 - Invited talk
- Talk at the *Journée de Bilan de la Chaire MMSN* at Ecole Polytechnique, September 2009
- Talk at the *Berichtskolloquium GRK 1294*, Karlsruhe Institute of Technology, December 2009
- Talk at the INRIA project POEMS seminar, ENSTA, Paris December 2009.

O. Pantz

- Workshop MOSICOB, September 2009 – Invited speaker
- AMIS09, Tizi-Ouzou, Algeria, March 2009 – Invited Professor for lectures on FreeFem++
- Ateliers de Simulation Numérique, Setif, Algeria, October 2009 – Invited Professor for lectures on FreeFem++

10. Bibliography

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