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Project-Team defi

Shape reconstruction and identification

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Theme : Computational models and simulation

Activity
R *eport*

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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.

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2. Overall Objectives

2.1. Highlights

- DEFI organized the first workshop on "Inverse Problems for waves: Methods and Applications" at Ecole Polytechnique on March 29-30 2010 <http://www.cmap.polytechnique.fr/~defi/mmsn2010/welcome.html>. About 60 researchers joined this two-day conference that featured invited talks and poster sessions.

2.2. 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.

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 spaced 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 of 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 constraint 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.

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-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 build 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 from 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. Shape optimization in 2D (geometry and topology)

Participants: Olivier Pantz, Grégoire Allaire [correspondant].

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.

5.1.2. Shape optimization in 3D (geometry and topology)

Participant: Grégoire Allaire [correspondant].

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 three space dimensions. These routines have been written by G. Allaire, A. Kelly. A web page of this toolbox is available at <http://www.cmap.polytechnique.fr/~allaire/freemem3d.html>.

5.1.3. 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.

5.1.4. De-Homogenization

Participant: Olivier Pantz.

We have developed a code under Freefem++ that implements the De-Homogeneization 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.

5.1.5. Inverse shape problems for axisymmetric eddy current problems

Participants: Armin Lechleiter, Zixian Jiang.

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

5.2. Scilab and Matlab Toolboxes

5.2.1. Conformal mapping method

Participant: Housseem Haddar [correspondant].

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

5.2.2. Direct and inverse problems in waveguides

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

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

5.3. Softwares written in FORTRAN

5.3.1. *Samplings-2d*

Participant: Housseem 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/Middleware: Linux
- Programming language: Fortran
- Documentation: fichier

5.3.2. *Samplings-3d*

Participant: Housseem 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.

5.3.3. *Time domain samplings-2d*

Participants: Housseem Haddar [correspondant], Armin Lechleiter.

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

5.3.4. *Solver for the Bloch-Torrey pde*

Participant: Jing Rebecca Li-Schlittgen [correspondant].

We propose a numerical method for solving the Bloch-Torrey partial differential equation in multiple diffusion compartments to compute the bulk magnetization of a sample under the influence of a diffusion gradient. We couple a mass-conserving finite element discretization in space with a stable time discretization using an explicit Runge-Kutta-Chebyshev method. The code can be used for simulation in two and three dimensions and is written in Fortran 90.

6. New Results

6.1. Sampling methods for inverse scattering problems

6.1.1. *Sampling methods with time dependent data*

Participants: Housseem Haddar, Armin Lechleiter.

We considered the extension of the so-called Factorization method to far-field data in the time domain. For a Dirichlet scattering object and incident wave fronts, the inverse problem under investigation consists in characterizing the shape of the scattering object from the behaviour of the scattered field far from the obstacle (far-field measurements). We derive a self-adjoint factorization of the time-domain far-field operator and show that the middle operator of this factorization possesses a weak type of coercivity. This allows to prove range inclusions between the far-field operator and the time-domain Herglotz operator. This project continues joint work with P. Monk and Q. Chen from the University of Delaware, for time-domain inverse scattering with near-field measurements [17] and we aim to extend this theory to electromagnetic problems.

6.1.2. Inverse problems for periodic penetrable media

Participants: Armin Lechleiter, Dinh Liem Nguyen.

Imaging periodic penetrable scattering objects is of interest for non-destructive testing of photonic devices. The problem is motivated by the decreasing size of periodic structures in photonic devices, together with an increasing demand in fast non-destructive testing. In this project, linked to the thesis project of Dinh Liem Nguyen, we considered the problem of imaging a periodic penetrable structure from measurements of scattered electromagnetic waves. As a continuation of earlier work, we considered an electromagnetic problem for transverse magnetic waves (earlier work treats transverse electric fields). We treat the direct problem by a volumetric integral equation approach and construct a Factorization method [40]. In the next step, we aim to tackle the full 3D-Maxwell problem.

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

Participant: Housseem Haddar.

The RG-LSM algorithm has been introduced by Colton-Haddar 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 result 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 [25]. 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 approximate interface conditions (atc) would be appropriate. We first investigated the accuracy of a continuation method using atc for multilayered interfaces [26]. The second step would be to incorporate this procedure as a pre-processing of the reciprocity gap sampling method. A long time prospective of this work is to tackle the 3-D electromagnetic case.

6.1.4. Inverse scattering in 3D waveguides

Participant: Armin Lechleiter.

Time-harmonic acoustic waves in an ocean of finite height can be modeled by the Helmholtz equation inside a layer with suitable boundary conditions. Scattering in this geometry features phenomena unknown in free space: resonances might occur at special frequencies and wave fields consist of partly evanescent modes. Inverse scattering in waveguides hence needs to cope with energy loss and limited aperture data due to the planar geometry. In this project, we analyzed direct wave scattering in a 3D planar waveguide and showed that resonance frequencies do not exist for a certain class of bounded penetrable scatterers. More important, we proposed the Factorization method for solving inverse scattering problems in the 3D waveguide. This fast inversion method requires near-field data for special incident fields and we rigorously proved a method to generate this data from standard point sources. This is a joint project with Tilo Arens and Drossos Gintides (see [10]).

6.1.5. *Inverse scattering from screens with impedance boundary conditions*

Participants: Yosra Boukari, Housseem Haddar.

We are interested in solving the inverse problem of determining a screen (or a crack) from multi-static measurements of electromagnetic (or acoustic) scattered field at a given frequency. An impedance boundary condition is assumed to be verified at both faces of the screen. We extended in a first step the use of the linear sampling method and the reciprocity-gap sampling method to retrieve the shape of the screen [32] and we are currently finalizing the theoretical justification of the so-called factorization method. We pursue the analysis of 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 conducted in collaboration with F. Ben Hassen.

6.1.6. *Transmission Eigenvalues and their application to the identification problem*

Participants: Anne Cossonnière, Housseem 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 multi-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.

The main topic of the PhD thesis of A. Cossonnière is to extend some of the results obtained above (for the scalar problem) to the Maxwell's problem. In this perspective, theoretical results related to solutions of the interior transmission problem for medium with cavities and existence of transmission eigenvalues have been obtained [37]. In collaboration with M. Fares and F. Collino from CERFACS we investigated the use of an integral equation approach to find the transmission eigenvalues for inclusions with piecewise constant index. The main difficulty behind this procedure is the compactness of the obtained integral operator in usual Sobolev spaces associated with the forward scattering problem. We solved this difficulty by introducing a preconditioning operator associated with a "coercive" transmission problem. The obtained procedure has been validated numerically in 2D and 3D cases. We are currently extending this work to the case of medium with perfectly conducting inclusions.

6.2. Iterative Methods for Non-linear Inverse Problems

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

Participants: Housseem Haddar, Zixian Jiang, Armin Lechleiter.

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

6.2.2. *Hybrid methods for inverse scattering problems*

Participants: Grégoire Allaire, Houssem Haddar, Dimitri Nicolas.

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

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

6.2.3. *Inverse Scattering by means of shape optimization*

Participant: Olivier Pantz.

We have investigated a new strategy based on the shape optimization method in order to recover the shape of a perfect conductor based on measures of the fields it scattered when enlightened by planar waves. The method consists in minimizing a cost function with respect to the shape of a "guessed" conductor. In a previous work, we have implemented this method using the standard quadratic differences between the scattered fields of the "target" and "guessed" conductors as cost-function. We have extended this method to another cost-function that could be seen as a relaxation of the previous one. This work has been conducted by V. Vostrikov under the supervision of O. Pantz in the context of an internship. A code has been developed to implement this new approach and has been concluded by a final report.

6.2.4. *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 $\Psi : B \rightarrow D$ 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 [20]. We currently investigate the extension to the case of electrode-type measurements.

6.2.5. *Inverse source problem related to contaminants transport with adsorption in porous media*

Participants: Aziz Darouichi, Houssem Haddar.

Soil and groundwater contamination by organic compounds have increasingly become a major environmental concern. This contamination can typically arise from an accidental or deliberate spills of some substances, like an industrial solvent, gasoline or other organic products, during the production, the transport or the storage of these constituents. These substances constitute a real threat to groundwater contamination since they constitute a long term source of contamination by dissolving during infiltrating rainwater, flooding ..., and furthermore presenting a health hazard and peril to inhabitants living next to these areas. The modelling of this phenomena necessitates the knowledge of certain physical parameters which are very often unknown or poorly known (dispersion, initial concentration of the pollutant, adsorption isotherms, ...).

As first investigations, we considered the inverse source problem related to contaminant transport in porous media with adsorption in equilibrium mode, where the data are final measurements of the contaminant concentration. The underlying forward model is an advective-dispersive transport equation coupled with a mass balance equation for the stationary water phase. We solved the inverse problem using a weighted cost functional combined with a regularization of the gradient. The convergence of the method is proved for simplified configurations. The unique identification is however still an open problem for this model. The extension to nonlinear transport problems is under study.

6.3. Shape and topological optimization methods

6.3.1. Topological optimal design problems for unsteady state equations

Participant: Grégoire Allaire.

Homogenization is one of possible methods of topological optimization and its principle is as follows. Consider a structural optimization problem in which it is to find how to place two different materials (eg, a solid but heavy one and a light but fragile one). The homogenization method consists in not only optimize the interface between the two phases, but also to consider all "fine" blends of the two phases, that is to say all composite materials that can be built with. Therefore, the new optimization variable will be the local percentage of the two phases (also with the effective tensor that represents the composite underlying microstructure). This view is radically different from the classical point of view which is more geometric: we switch from a method of shape tracking to a method of shape capturing where the topology may change without any constraints. The success of this approach are immense for about twenty years now, but still there is a need for many generalizations or mathematical justifications.

For instance, in the article [8] we considered this type of shape optimization problem where the state equation is unsteady of parabolic type. We show in particular that the relaxation process by homogenization and the stationary limit for large time commute. In other words, the optimal composites in the parabolic case (which have a more complicated structure than in the stationary case) become simpler as time goes to infinity.

In the article [5] we consider another unsteady state equation of the wave type. An additional difficulty is the consideration of objective functions depending not only on the solution of the equation but also on its gradient. In this case the method of homogenization cannot be implemented due to lack of knowledge of all possible pairs of effective tensors and correctors for the gradients for composites obtained by homogenization. It is a difficult open problem under investigation of many researchers. We propose to solve it under an important simplification: we assume that both initial phases properties are very close (we then say that their contrast is small). It is then possible, based on the (small) contrast setting, to perform a Taylor expansion of the problem up to the second order. We can then relax the problem and in this case the homogenization method is replaced by the theory of H -measures (easier ultimately) introduced by P. Gerard and L. Tartar. In addition to obtaining rigorous relaxation results for this structural optimization problem "with small contrast", we propose a numerical method of topological type for evaluating the optimal shapes.

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 in previous works (see bibliography of 2009). Since that time, the method has been improved and a new article presenting the last results is in preparation. Moreover, we intend to extend this approach to other kinds of cost functions. A first attempt, based on a gradient method, has been made. Unfortunately, it was leading to local minima. Thus a new strategy has to be worked out. It will be mainly based on the same ideas than the one developed for the compliance minimization problem, but some difficulties are still to be overcome.

6.3.3. A new Liouville type Rigidity Theorem

Participant: Olivier Pantz.

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

6.4. Asymptotic models

6.4.1. Modeling and numerical methods for the study underground storage of waste

Participant: Grégoire Allaire.

On the topic "Numerical multi-scale simulations" I work in collaboration with Philippe Montarnal and Thomas Abballe from CEA. We work on the extension of a multiscale finite element method to a finite volume framework with an application to the diffusion of chemical species in concrete. We rely on one of my previous works with Robert Brizzi at Ecole Polytechnique, where we developed a new multiscale finite element method that allows to perform a numerical homogenization. The principle is to build a basis of finite elements that contains information on the heterogeneity of the underlying medium. We can then make precise calculations without having to use of very fine mesh size (smaller than the characteristic size of the heterogeneities). We successfully extended this approach to finite volume method (more adapted to diffusivity high contrasts) in 2D and 3D within the framework of TRIO-U code. An article, based on the presentation of Thomas Abballe in NTMC'09 Congress (New Trends in Model Coupling), has been published on this subject [2].

The second topic on the hydrodynamic dispersion, is a collaboration with Robert Brizzi (CMAP), Andro Mikelic (Lyon 1) and Andrey Piatnitski (Narvik). It consists in finding macroscopic models for transport and dispersion of chemical species in flows within porous media and in presence of chemical reactions. Given the fluid speed field, the microscopic equations are of the convection-diffusion-reaction with two possible fields: the concentration in the fluid and the one on the solid surface of the pores. Using a homogenization

method (more precisely two-scale convergence with drift) we obtain a new effective model where the homogenized coefficients obtained from microscopic cell problems combine the three aspects (convection, diffusion, chemical reactions) in a strongly coupled form. One can then study the dependence of the effective dispersion tensor with respect to the Peclet and the Damkohler dimensionless numbers. Numerical simulations indicate that the asymptotic behavior of the dispersion for large Peclet numbers are radically different in the presence or in the absence of chemical reactions. Our work is published in [6], cite63.

Moreover, with Andrey Piatnitski we showed in [9] that a reaction-diffusion model in porous media with periodically time oscillating coefficients (for example, as a result of a cyclical external forcing) can lead at the macroscopic level to a significant convection effect. This surprising effect, also studied by other authors, is one of the possible explanations for the mechanism of bio-engines. In the context of waste storage in porous media, it could be responsible for transportation of radionuclide larger than one would predict from microscopic flow velocities.

Finally, and more recently with the same people we are interested in the homogenization of microscopic models of clays. More generally, this work is part of a collaboration with the GDR PARIS and the team of chemists around Pierre Turq. In a first step we considered the mechanism of electrophoresis in porous media for which there are already many homogenized models in the literature of physics or mechanics. We mathematically justified this homogenization process in a linearized case (a usual assumption in previous works) and we formally derived a new homogenized model in the nonlinear case. We published an article on the subject [7].

6.4.2. Interface conditions for thin dielectrics

Participant: Housseem 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 [18].

Jointly with B. Delourme and P. Joly we investigated 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, 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 [38]. The case of 3-D Maxwell's equations is under preparation.

6.4.3. Generalized Impedance Boundary Conditions: the inverse problem

Participants: Nicolas Chaulet, Housseem Haddar.

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 collaboration with L. Bourgeois we continued the investigation of the problem of unique identification and stability of the reconstruction of $Z = \mu\Delta_\Gamma + \lambda$ from the knowledge of the far fields created by one or several incident plane waves at a fixed frequency. We first derived a new type of stability estimate for the identification of λ and μ from the far field when inexact knowledge of the boundary is assumed. We then introduced an optimization method to identify λ and μ , using in particular a H^1 -type regularization of the gradient. We also conducted some numerical validation in two dimensions, including a study of the impact of some various parameters, and by assuming either an exact knowledge of the shape of the obstacle or an approximate one [33]. We are currently finalizing a work on simultaneous reconstruction of the GIBC and the shape of the obstacle from the knowledge of the farfield operator using a nonlinear optimization method.

6.5. Scattering from Rough Unbounded Penetrable Layers

Participants: Housseem 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 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 in 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 [39]. 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. 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 is on the simulation of aortic valves, where complex self-contacts between the valves could occur. 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 [27]. 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 were developed under Freefem++ and C++.

6.7. Investigating water diffusion in biological tissue: with application to anatomical and functional neuroimaging

Participant: Jing Rebecca Li-Schlittgen.

Water diffusion in biological tissues is not free (Gaussian), as the signal attenuation is not monoexponential with diffusion-weighting (b value). Some groups have successfully characterized this attenuation with a biexponential model, which suggests the presence of 2 water pools in slow or intermediate exchange. However, this model is still controversial and the nature of the 2 pools (e.g., membrane-bound and intra/extracellular bulk water) remains elusive. We proposed a semi-analytical model of multiple-compartment diffusion. We consider the Bloch-Torrey partial differential equation model (PDE in time and space) for the magnetization and show that because the diffusion MRI signal is the integral of the magnetization, we can formulate an ordinary differential equation (ODE only in time) directly on the signal. This makes the inverse problem of determining biological parameters from the DMRI signal more numerically tractable, as the number of unknowns is vastly reduced. At the same time, the link between the biological properties of diffusion in the different compartments and the overall signal is made more direct and will aid in the more straightforward interpretation of the DMRI signals in terms of the underlying physical properties of water diffusion in tissue. This model is more general than the widely used Karger model because it takes into account the geometry of the cellular structure. This work is conducted in collaboration with D. Calhoun (CEA, Saclay), C-H. Yeh (National Yang-Ming University, Taiwan, CEA, Saclay), C. Poupon (CEA Neurospin, Saclay) and D. Le Bihan (CEA Neurospin, Saclay).

7. Contracts and Grants with Industry

7.1. DGA: Oct. 2009 - Sep. 2012

Participants: Nicolas Chaulet, Housseem Haddar.

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: Oct. 2008 - Sep. 2011

Participants: Anne Cossonnière, Housseem Haddar.

This grant is managed 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. EDF R&D : 2010

Participants: Housseem Haddar, Zixian Jiang, Armin Lechleiter.

We initiated collaboration with the group SDTI (EDF-R&D, Chatou) on non destructive testing of magnetic deposits on PWR fuel rods. The grant in 2010 (50KE) provided for instance financial support of a Master M2 training.

7.4. ANR, program Cosinus, 2010-2013

Participants: Jing Rebecca Li-Schlittgen, Housseem Haddar, Armin Lechleiter.

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

7.5. Contracts managed by Ecole Polytechnique

Participant: Grégoire Allaire.

- Contract with IFP for the supervision of the PhD thesis of F. Ouaki on multiscale finite element methods for two-phase flow in porous media (defense planned in 2013).
- Contract with EADS for the supervision of the PhD thesis of G. Delgado on the topological shape optimization for draping composite materials (defense planned in 2013).
- Contract with Renault for the supervision of the PhD theses of Ch. Dapogny on the optimization of geometric shapes (Co-supervised with P. Frey, defense planned in 2013), and G. Michailidis on shape optimization with topological constraints (co-supervisor with F. Jouve, defense planned in 2013).

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 least 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++).

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/ISIP/isip.html>. This team is lead by H. Haddar (DeFI) and F. Cakoni (UDEL).
- Since 2011 we initiated a PHC PROCOPE program with the University of Goettingen on “Inverse scattering in the time domain”. This team is lead by A. Lechleiter (DeFI) D. Russell Luke (University of Goettingen).
- 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

- O. Ozdemir, Associate Professor from ITU: January 2010 and July-August 2010.
- F. Cakoni, Professor from the University of Delaware: November 21-27 2010.

- D. Colton, Professor from the University of Delaware: November 21-27 2010.
- R. Kress, Professor from the university of Goettingen: 19-24 May 2010.
- F. Ben Hassen from LAMSIN, ENIT: December 15 to December 22, 2010.
- Abdelghani Benjouad, Ecole Mohammadia des Ingenieurs, December, 2010.

9. Dissemination

9.1. Scientific Community Animation

- G. Allaire organized "Journée de Bilan de la Chaire MMSN" - October, 2010.
- H. Haddar and A. Lechleiter organized, jointly with F. Cakoni, the first workshop on "Inverse Problems for waves: methods and applications" at Ecole Polytechnique on March 29-30 2010. About 60 researchers joined this two-day conference that featured invited talks and poster sessions.
- H. Haddar organized, jointly with M. Bonnet, a GAMNI/AFM Minisymposium *Imagerie et identification* at the conference CANUM 2010 (40e Congrès National d'Analyse Numérique), June 2010, Carcans-Maubuisson.
- J.R. Li is the organizer of mini-symposium "Advances in applied numerical methods for complex applications", ICIAM 2011, 7th International Congress on Industrial and Applied Mathematics.
- A. Lechleiter is responsible of the workgroup seminar of DeFI see <http://www.cmap.polytechnique.fr/~defi/events.html>.

9.2. Collective Responsibilities

- G. Allaire is
 - President and Vice-Chairman, Department of Applied Mathematics Ecole Polytechnique.
 - Chairman of the Scientific Council of the GNR MOMAS (Mathematical Modelling and Numerical simulations of problems related to management of nuclear waste).
 - Member of the Board of SMAI (Society of Applied and Industrial Mathematics).
 - Member of the Board of Directors of the IHP (Institut Henri Poincaré) since 2010.
 - Member of the Evaluation Committee of INRIA Grenoble Rhône-Alpes (2010).
 - Co-editor in chief of the series "Mathematics and Applications of SMAI published by Springer.
 - Member of the editorial boards of newspapers ESAIM / COCV since 2000 SIAM Multi-scale 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'Università di Ferrara since 2008.
- H. Haddar is member of the scientific committee of the CMAP and INRIA Scalay Ile de France.
- J.-R. Li is associate editor of SIAM Journal on Scientific Computing.

9.3. Teaching

G. Allaire

- Course "Analyse Numérique et d'Optimisation", for students (~ 280) 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 ~ 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 ~ 20) in the second year of Ecole Polytechnique curriculum.
- Working groups of the course “Conception optimale des structures”, for students (~ 30) in the third year of Ecole Polytechnique curriculum.
- Project training in Numerical Analysis (2 projects - "Brittle detection" and "Dynamic of Vesicles")
- Workshop FreeFem++ (Université Pierre et Marie-Curie) - An Introduction courses in FreeFem++ and computer session.
- FreeFem++ courses at the LERMA of the EMI (Rabat) (1 week: courses and computer sessions)

9.4. Seminars, Conferences, Visits

G. Allaire

- Final Conference of the ANR MICA Tours (2010).
- Workshop on Inverse Problems for Waves, Ecole Polytechnique, Palaiseau (March 2010).
- European Conference on Computational Mechanics, Paris (May 2010).
- Conference on Multi-Scale Analysis and Homogenization, Indian Institute of Science, Bangalore (July 2010).
- 10th Franco-Romanian Colloquium in Applied Mathematics, Poitiers (August 2010).
- Colloquium "Multi-scale Problems in Sustainable Resource Management", Amsterdam (September 2010).
- Inauguration of the Schlumberger Chair IHES, Bures sur Yvette (November 2010).

H. Haddar

- Picof’ 10 conference in Cartagena Spain) 7-9 April, 2010, invited planary talk.
- Talk in the minisymposium on *Inverse Problems* at the 8th AIMS International Conference on Dynamical Systems, Differential Equations and Applications, Dresden, may 2010, Germany.

- Séminaire de Mathématiques Appliquées de l'Université de Metz, May 21, 2010.
- Invited for one weak research visit at LAMSIN, July 2010.
- Journée Bilan Chaire MMSN (October 2010).
- Séminaire de Mathématiques Appliquées du Collège de France, November 12, 2010.

A. Lechleiter

- invited talk in the Young Researchers Minisymposium on *Numerical and Analytical Methods for Problems with Multiple Scales* at the annual GAMM conference, march 2010, Karlsruhe, Germany.
- Talk in the minisymposium on *Inverse Problems* at IV European Congress on Computational Mechanics (ECCM IV), may 2010, Paris.
- Talk in the minisymposium on *Inverse Problems* at the 8th AIMS International Conference on Dynamical Systems, Differential Equations and Applications, Dresden, may 2010, Germany.
- Talk in the Gamni/AFM Minisymposium *Imagerie et identification* at the conference CANUM 2010 (40e Congrès National d'Analyse Numérique), june 2010, Carcans-Maubuisson.

J.-R. Li

- The International Society for Magnetic Resonance in Medicine (ISMRM) annual meeting, Stockholm, May, 2010.
- IMA Hot Topics Workshop: Integral Equation Methods, Fast Algorithms and Applications, August 2-5, 2010.

O. Pantz

- Mathematical Fluid Dynamics and its applications (June 21 - 24 2010) – Invited speaker
- 15th International Conference on Methods and Models in Automation and Robotics, August 2010 – Invited speaker
- Journée Bilan Chaire MMSN (October 2010).

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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Articles in International Peer-Reviewed Journal

- [2] T. ABBALLE, G. ALLAIRE, E. LAUCOIN, P. MONTARNAL. *Application of a coupled FV/FE multiscale method to cement media*, in "Networks and Heterogeneous Media", 2010, vol. 5, n^o 3, p. 603-615.
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