BOOK OF ABSTRACTS

SS8 - Advances in inverse problems: theory, algorithms, and applications

2nd Joint Meeting Brazil-Italy in Mathematics

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Organizers:

Antonio Leitao, Federal University of Santa Catarina
Alexandre Kawano, University of São Paulo
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Passive underwater hearing by measurements in vibrating beams

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We investigate an inverse source problem for a coupled fluid–structure system composed of an ideal acoustic fluid occupying a rectangular tank and a structural component located at its bottom boundary. The dynamics are driven by two sources acting synchronously in time: a fluid source of the form $g(t)f_1(x)$ distributed within the fluid domain, and a structure source of the form $g(t)f_2(x)$ applied directly to the elastic boundary, where the temporal profile $g \in C^1$ is assumed to satisfy $g(0) \neq 0$. The unknown spatial source terms f_1 and f_2 are taken in the Sobolev spaces H^{-1} and H^{-2}, respectively. Our main result establishes uniqueness in the corresponding inverse problem: from partial and localized measurements of the displacement field, performed either in the fluid region or on the structural component, on a nonempty open subset and over a sufficiently short time interval, it is possible to recover uniquely the pair (f_1, f_2). In particular, this shows that one can distinguish the fluid-borne contribution from the structure-borne one despite the coupling of the system. The proof combines a spectral analysis based on an eigenvalue formulation with a coupling argument relying on the method of spherical means.

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An All-at-Once Formulation for a Finite-Mode 2.5D Electrical Resistivity Tomography Inverse Problem

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This work presents an all-at-once formulation [2] for a finite-mode two-and-a-half-dimensional (2.5D) electrical resistivity tomography inverse problem based on the classical Fourier-domain formulation of Dey and Morrison [1]. Unlike the original model, which employs point current sources, the proposed formulation considers localized volumetric current sources and bounded observation functionals acting on the electric potential. These modifications yield a mathematically convenient forward model whose state variables naturally belong to Sobolev spaces, thereby avoiding the singularities associated with point sources and the unboundedness of pointwise observations.

The forward problem is formulated as a finite collection of modal boundary value problems obtained through a cosine transform in the invariant direction. The resulting inverse problem is written in an all-at-once form, where the conductivity and the modal potentials are treated as independent optimization variables. The conductivity is constrained to satisfy physically meaningful bounds and is regularized by total variation, while the state variables are regularized in higher-order Sobolev spaces.

The proposed formulation is shown to fit within the abstract all-at-once regularization framework of [3]. In particular, the model operator is shown to be sequentially closed, the observation operator is continuous, and the admissible sets satisfy the compactness properties required for the existence, stability and convergence results.

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Unique identification of a rigid inclusion in an elastic nanoplate from a single measurement

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In this talk, we consider the inverse problem of determining a rigid inclusion inside an elastic nanoplate. The nanoplate is modeled within the simplified strain-gradient linear elasticity theory [1], with the Kirchhoff–Love kinematics, and is subjected to flexural deformation induced by prescribed couple and transverse force fields applied at the boundary of the nanopate. Under suitable ellipticity and regularity assumptions on the coefficients of the nanoplate and on the boundary of the inclusion, we prove that knowledge of the transverse displacement and of its first and second normal derivatives on an open portion of the boundary of the nanoplate is sufficient to uniquely determine the rigid inclusion. The main tools in the proof are the uniqueness of the solution to the Cauchy problem for a nanoplate and a quantitative estimate of unique continuation in the form of a three–spheres inequality [2] for solutions to the sixth–order homogeneous elliptic differential equation governing the flexural equilibrium of the nanoplate.

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THERMAL CHARACTERIZATION OF FUNGAL COLONIES

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Fungi have significant relevance in various industrial and healthcare applications. Detecting contamination by these microorganisms is essential to prevent food intoxication in humans and domesticated mammals. Such intoxication occurs when mycotoxins, secondary metabolites produced by fungi during metabolization, are present in food. In some cases, detecting mycotoxins is expensive and more time-consuming than identifying the fungi themselves. Developing a methodology for early-stage fungal detection using thermography is one of several approaches that can be employed to achieve this objective. The objective of this study was to estimate the thermophysical properties of Aspergillus brasiliensis, a filamentous fungus frequently found in diverse environments. A Bayesian framework was considered for the inverse problem solutions, involving the estimation of the volumetric heat capacity and thermal conductivity of this fungus under different growth stages. A Petri dish containing the fungus was heated in a biological incubator and allowed to cool down to ambient temperature, while surface temperature measurements of the fungus were obtained using an infrared camera. Different heat conduction problems and their associated inverse problems were addressed and the parameters of interest were estimated using a Markov Chain Monte Carlo (MCMC) method. A statistical analysis was performed to assess the quality of the estimations, examine the influence of experimental factors, and evaluate the consistency of the results obtained with different samples [1-3].

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Integrating Machine Learning and Variational Regularization in Electrical Impedance Tomography.

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Electrical Impedance Tomography (EIT) is a prominent inverse problem with applications ranging from medical imaging to non-destructive testing. It involves imaging electrical properties of a medium from indirect observations, specifically boundary voltage measurements induced by injected surface currents. Mathematically, this is formulated as the non-linear and ill-posed challenge of recovering an unknown coefficient within a Partial Differential Equation (PDE) model.

In this talk, I will present two reconstruction methods for EIT based both on variational regularization and on (supervised) machine learning. Highlighting the fruitful intersection of functional analysis, machine learning, and scientific computing, I will discuss both the theoretical guarantees of such techniques and their numerical performances.

The first approach focuses on a non-smooth optimization problem featuring a sparsity-promoting regularization term. This classical model is enhanced by a data-driven support estimation utilizing a suitably trained Graph Neural Network (GNN). Aside from yielding compelling reconstructions, the proposed algorithm comes with rigorous theoretical guarantees regarding its stability and convergence, leveraging connections with compressed sensing theory.

The second method builds upon the algorithmic unfolding paradigm to address the highly complex, real-world application of multi-frequency EIT. It exploits the expressive power of GNNs in place of standard proximal operators within a quasi-Newton scheme for a constrained non-smooth optimization problem. After describing the additional challenges and potential advantages of multi-frequency measurements in EIT, I will discuss the theoretical and numerical results associated with this technique.

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Lipschitz Stability for Polyhedral Elastic Inclusions from Partial Data

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We deal with the inverse problem of determining a polyhedral inclusion compactly contained in an elastic body from boundary measurements of traction and displacement taken on an open portion of the boundary. Both the inclusion and the body are made of homogeneous isotropic material. Under suitable assumptions on the geometry of the unknown inclusion, we prove a constructive Lipschitz stability estimate from the local Dirichlet-to-Neumann map. The main tools of our approach are quantitative estimates of unique continuation, the construction of singular solutions to the Lamé system, a boundary formula for the Gateaux derivative of the Dirichlet-to-Neumann map with respect to a deformation homotopy, and the determination of a lower bound of this derivative using, among other tools, the Rongved biphase fundamental solution for the Lamé system. To the authors' knowledge, this is the first stability result in the determination of polyhedral elastic inclusions in linear elasticity by boundary value data. This is based on a joint work with A. Aspri, E. Beretta, E. Francini, A. Morassi, E. Rosset, S. Vessella.

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