

反问题分析与计算研讨会

Workshop on Analysis and
Computation of Inverse Problems

哈尔滨工业大学 数学学院

2021年4月17-18日

一、会议简介

反问题是现代数学物理和计算数学中的一个十分活跃的重要研究领域，在近半个世纪内，一直受到了国内外众多的数学家、物理学家以及工程技术专家的广泛关注。近些年，关于反问题的理论不断被发展与完善，相关的数学理论和数值方法研究在科学计算中日益活跃，其研究内容越来越丰富，相关应用已经遍及医学成像、雷达探测、地质勘探、光学、材料和控制等众多重要的科学技术领域。因此，从数学理论和计算方法角度，对反问题给予必要的基础研究，对物理现象的定性解释和定量预测都显得至关重要，相关研究不仅具有重要的科学意义，而且部分研究成果能够直接促进工业生产与发展。

为了探讨反问题领域的最新发展和前景，加强研究机构和高校在反问题研究领域的学术交流与合作，拟定于2021年4月17-18日在线举办“反问题分析与计算研讨会”。会议主题包括：反问题和不适定问题的理论和正则化方法、偏微分方程和反问题数值方法、统计反问题和求解反问题的机器学习技术等。

会议时间：

2021年4月17日—4月18日

组织委员会：

韩波 马坚伟 陈勇 郭玉坤 汪贤超

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二、会议日程表

2021年4月17日，周六上午

腾讯会议 链接: <https://meeting.tencent.com/s/tWOyW62v26bF>

会议号: 230 185 751 会议密码: 0417

时间	报告人	报告题目
08:30-08:40	开幕式	
主持人: 韩波		
08:40-09:10	李景治 南方科技大学	Determining a random Schrödinger operator: both potential and source are random
09:10-09:40	邓又军 中南大学	Localized resonance and its applications in imaging and cloaking
09:40-10:10	刁怀安 东北师范大学	On a local geometric property of the generalized elastic transmission eigenfunctions and application
10:10-10:20	休息	
主持人: 马坚伟		
10:20-10:50	窦芳芳 电子科技大学	Conditional stability for the Cauchy problem of the Ginzburg-Landau equation
10:50-11:20	赖俊 浙江大学	Forward and inverse scattering from axisymmetric objects based on integral equations
11:20-11:50	刘晓东 中国科学院	直接采样法的新进展
12:00-14:00	午休	

二、会议日程表

2021年4月17日，周六下午

腾讯会议 链接：<https://meeting.tencent.com/s/tWOyW62v26bF>

会议号：230 185 751 会议密码：0417

时间	报告人	报告题目
主持人：李景治		
14:00-14:30	杨家青 西安交通大学	On recovery of the interface between the fluid and piezoelectric material
14:30-15:00	高忆先 东北师范大学	Electromagnetic field enhancement in a subwavelength rectangular open cavity
15:00-15:30	张海文 中国科学院	Near-field Imaging of an Unbounded Elastic Rough Surface with a Direct Imaging Method
15:30-15:40	休息	
主持人：刘晓东		
15:40-16:10	闫亮 东南大学	Adaptive Surrogate Modeling Based on Deep Neural Networks for Bayesian Inverse Problems
16:10-16:40	郑光辉 湖南大学	Reaction coefficient inversion in nonlocal diffusion
16:40-17:10	张磊 黑龙江大学	Analysis and calculation for the scattering and inverse problems in complex backgrounds

二、会议日程表

2021年4月18日，周日上午

腾讯会议 链接：<https://meeting.tencent.com/s/sBKQB3ozXH3n>

会议号：528 365 280 会议密码：0418

时间	报告人	报告题目
主持人：陈勇		
08:10-08:40	董和平 吉林大学	Inverse obstacle scattering for acoustic waves in the time domain
08:40-09:10	王海兵 东南大学	Domain sampling methods for inverse boundary value problems
09:10-09:40	徐翔 浙江大学	Inverse Spectral Problems Based on Trace Formulas
09:40-10:10	江渝 上海财经大学	地铁交通大数据中的反问题
10:10-10:20	休息	
主持人：郭玉坤		
10:20-10:50	刘可伋 上海财经大学	A free boundary problem modeling the ductal carcinoma in situ
10:50-11:20	贾骏雄 西安交通大学	Stein variational gradient descent (SVGD) for functions and applications to statistical inverse problems
11:20-11:50	孟世旭 中国科学院	波导介质采样法的进展
会议闭幕		

三、报告摘要(按姓氏首字母排序)

1. 邓又军 中南大学

题目: Localized resonance and its applications in imaging and cloaking

摘要: In this talk, we shall introduce the notions of localized resonances. Usually these problems are related to the spectral of the Neumann-Poincare operators in different models. As an example, we provide a mathematical framework for localized plasmon resonance of nanoparticles. Using layer potential techniques associated with the full Maxwell equations, we derive small-volume expansions for the electro-magnetic fields, which are uniformly valid with respect to the nanoparticle's bulk electron relaxation rate. Then, we discuss the scattering and absorption enhancements by plasmon resonant nanoparticles. Finally, we show the applications of localized resonance in imaging and cloaking.

2. 刁怀安 东北师范大学

题目: On a local geometric property of the generalized elastic transmission eigenfunctions and application

摘要: Consider the nonlinear and completely continuous scattering map

$$S\left((\Omega; \lambda, \mu, V), \mathbf{u}^i\right) = \mathbf{u}_t^\infty(\hat{\mathbf{x}}), \quad \hat{\mathbf{x}} \in \mathcal{S}^{n-1},$$

which sends an inhomogeneous elastic scatterer $(\Omega; \lambda, \mu, V)$ to its far-field pattern \mathbf{u}_t^∞ due to an incident wave field \mathbf{u}^i via the Lamé system. Here, (λ, μ, V) signifies the medium configuration of an elastic scatterer that is compactly supported in Ω . In this talk, we are concerned with the intrinsic geometric structure of the kernel space of \mathcal{S} , which is of fundamental importance to the theory of inverse scattering and invisibility cloaking for elastic waves and has received considerable attention recently. It turns out that the study is contained in analysing the geometric properties of a certain non-selfadjoint and non-elliptic transmission eigenvalue problem. We propose a generalized elastic transmission eigenvalue problem and prove that the transmission eigenfunctions vanish locally around a corner of $\partial\Omega$ under generic regularity criteria. The regularity criteria are characterized by the Hölder continuity or a certain Fourier extension property of the transmission eigenfunctions. As an interesting and significant application, we apply the local geometric property to derive several novel unique identifiability results for a longstanding inverse elastic problem by a single far-field measurement.

3. 董和平 吉林大学

题目: Inverse obstacle scattering for acoustic waves in the time domain

摘要: This talk concerns an inverse acoustic scattering problem which is to determine the location and shape of a rigid obstacle from time domain scattered field data. An efficient convolution quadrature method combined with nonlinear integral equation method is proposed to solve the inverse problem. In particular, replacing the classic Fourier transform with the convolution quadrature method for time discretization, the boundary integral equations for the Helmholtz equation with complex wave numbers can be obtained to guarantee the numerically approximate causality property of the scattered field under some condition. Numerical experiments are presented to demonstrate the effectiveness and robustness of the proposed method.

4. 窦芳芳 电子科技大学

题目: Conditional stability for the Cauchy problem of the Ginzburg-Landau equation

摘要: The Ginzburg-Landau equation lies in the heart of the general theory of superconductors and is studied extensively. In this talk, we focus on the problem of determining the solution of the equation by measurement on a subset the boundary of the domain where the equation evolved. This is not studied in the literature. We employ a global Carleman to solve that problem. The main difficulty comes from the cubic nonlinear term in the equation, which cannot be handled by linearized method.

5. 高忆先 东北师范大学

题目: Electromagnetic field enhancement in a subwavelength rectangular open cavity

摘要: Consider the transverse magnetic polarization of the electromagnetic scattering of a plane wave by a perfectly conducting plane surface, which contains a two-dimensional subwavelength rectangular cavity. The enhancement is investigated fully for the electric and magnetic fields arising in such an interaction. The cavity wall is assumed to be a perfect electric conductor, while the cavity bottom is allowed to be either a perfect electric conductor or a perfect magnetic conductor. We show that the significant field enhancement may be achieved in both nonresonant and resonant regimes. The proofs are based on variational approaches, layer potential techniques, boundary integral equations, and asymptotic analysis. Numerical experiments are also

presented to confirm the theoretical findings.

6. 贾骏雄 西安交通大学

题目：Stein variational gradient descent (SVGD) for functions and applications to statistical inverse problems

摘要：For solving Bayesian inverse problems governed by large-scale forward problems, we present an infinite-dimensional version of the Stein variational gradient descent (iSVGD) method, which has the ability to generate approximate samples from the posteriors efficiently. Specifically, we introduce the concept of the operator-valued kernel and the corresponding function-valued reproducing kernel Hilbert space (RKHS). Through the properties of RKHS, we give an explicit meaning of the infinite-dimensional objects (e.g., the Stein operator) and prove that the infinite-dimensional objects are indeed the limit of finite-dimensional items. Furthermore, by generalizing the change of variables formula, we construct iSVGD with preconditioning operators, yielding more efficient iSVGD. During these generalizations, we introduce a regularity parameter $s \in [0,1]$. Our analysis shows that the intuitive trivial version (i.e., by directly taking finite-dimensional objects as infinite-dimensional items) of iSVGD with preconditioning operators ($s=0$) will yield inaccurate estimates, and the parameter s should be chosen larger than 0 and smaller than 0.5. Finally, the proposed algorithms are applied to an inverse problem governed by the Helmholtz equation. Numerical results confirm the correctness of our theoretical findings and demonstrate the potential usefulness of the proposed approach in the posterior sampling of large-scale nonlinear statistical inverse problems.

7. 江 渝 上海财经大学

题目：地铁交通大数据中的反问题

摘要：随着我国城市规模和经济建设飞速的发展，城市化进程在逐步加快。以轨道交通为骨干的公共交通体系为城市居民提供安全、快速、舒适的交通环境的同时，也成为了解决大城市交通拥堵、环境污染问题的主要途径。利用轨道交通进出站大数据，实时掌握路网中各个站点的客流存量和各条线路上客流负载信息，及时准确对路网超负载的可能位置和时间作出预警，进而通过限流、调整行车间隔等手段有效控制引导客流，有效防控事故风险、提高乘客乘车舒适度，是路网精细化管理中最重要的课题。我们建立了基于公共交通卡数据对城市轨道线网客流数据进行反演的模型与算法，利用该模型和算法对大事件发生前后线网各站点的客流存量进行了分析和重构。反演得到的客流数据可以客观反映大事件的发生随时间变化对发生站点和邻近站点的影响。在此基础上，定义了城市轨道交通线网每个站点的大事件影响因子，该影响因子可以比较客观地反映大事件对各个站点的影响程度。实证分析证明了基于公共交通卡数据的城市轨道交通大事件影响分析模型的可靠性和有效性。

8. 刘晓东 中国科学院数学与系统科学研究院

题目：直接采样法的新进展

摘要：直接采样法继承了传统采样法不依赖散射目标先验信息的特点，在数值实施上更为简单且稳定性更强，使得其在过去十年得到数学家的很多关注。本报告将介绍我们对这个方法的理解和认识，以及我们在这个方向的一些思考和进展。

9. 李景治 南方科技大学

题目：Determining a random Schrödinger operator: both potential and source are random

摘要：We present an inverse scattering problem associated with a Schrödinger system where both the potential and source terms are random and unknown. The well-posedness of the forward scattering problem is first established in a proper sense. We then derive two unique recovery results in determining the rough strengths of the random source and the random potential, by using the corresponding far-field data. The first recovery result shows that a single realization of the passive scattering measurements uniquely recovers the rough strength of the random source. The second one shows that, by a single realization of the backscattering data, the rough strength of the random potential can be recovered. The ergodicity is used to establish the single realization recovery. The asymptotic arguments in our study are based on techniques from theory of pseudodifferential operators and microlocal analysis.

10. 刘可伋 上海财经大学

题目：A free boundary problem modeling the ductal carcinoma in situ

摘要：In this talk, we consider a nonlinear free boundary system for the nutrient concentration, which comes from the mathematical model of ductal carcinoma in situ (DCIS). The motion of the free boundary is given by an integro-differential equation. We will show the uniqueness and numerical methods for the forward problem. Moreover, some related inverse problems would be presented.

11. 赖俊 浙江大学

题目：Forward and inverse scattering from axisymmetric objects based on integral equations

摘要： Fast, high-accuracy algorithms for electromagnetic and elastic scattering from axisymmetric objects are of great importance for modeling physical phenomena in optics, materials science (e.g. meta-materials), and many other fields of applied science. In this talk, we develop an FFT-accelerated separation of variables solver that can be used to efficiently invert integral equation formulations of Maxwell's equations and Navier equations for scattering from axisymmetric bodies. The solver is also extended to geometries with non-smooth generating curves and large cavities. In the end, we also discuss the application of the fast and high-order solver in the inverse scattering to recover the objects with axis-symmetry.

12. 孟世旭 中国科学院数学与系统科学研究院

题目： 波导介质采样法的进展

摘要： 近些年来，波导介质的反散射问题引起了广泛关注。波导介质不同于全空间均匀介质，该介质在一个方向是无界的，而在其他方向是有界的（或者是分层的）。它在隧道、海洋、工程和无损检测等等有着非常重要性的应用。采样类方法，比如线性采样法和分解法，是一种非常有效的直接成像法，在数学和工程领域有着广泛的影响。我们将介绍波导介质中采样法的一些进展，包括具有未知扰动波导的声波反散射，部分数据下的成像，以及电磁波的采样类方法。

13. 王海兵 东南大学

题目： Domain sampling methods for inverse boundary value problems

摘要： In this talk, I will discuss the range test (RT) and no-response test (NRT) for the inverse boundary value problem for the Laplace equation. These testing methods are domain sampling methods to estimate the location of the obstacle D using test domains and the associated indicator functions. We will show the duality between these two methods in terms of the equivalence of the pre-indicator functions associated to their indicator functions. We will also give each of these reconstructions without using the duality if the Dirichlet data of the Cauchy data is not identically zero and the solution to the associated forward problem does not have any analytic extension across the boundary of the unknown target. Moreover, we will show that these methods can still give the reconstruction of D if D is a convex polygon and satisfies some specified conditions.

14. 徐翔 浙江大学

题目： Inverse spectral problems based on trace formulas

摘要: In this talk, we will discuss some recent progress on numerical algorithm for inverse spectral problem for the Sturm-Liouville, Euler-Bernoulli and damped wave operator. Instead of inverting the map from spectral data to unknown coefficients directly, we propose a novel method to reconstruct the coefficients based on inverting a sequence of trace formulas which bridge the spectral and geometry information clearly in terms of a series of nonlinear Fredholm integral equations. Numerical experiments are presented to verify the validity and effectiveness of the proposed numerical algorithm. The impact of different parameters involved in the algorithm is also discussed.

15. 闫 亮 东南大学

题目: Adaptive surrogate modeling based on deep neural networks for Bayesian inverse problems

摘要: Surrogate models are often constructed to speed up the computational procedure of the Bayesian inverse problems(BIPs), as the forward models can be very expensive to evaluate. However, due to the curse of dimensionality and the nonlinear concentration of the posterior, traditional surrogate approaches are still not feasible for large scale problems. This talk will survey our recent works in designing surrogate models using deep learning techniques. Several fast and efficient algorithms based on deep neural networks (DNN) to solve BIPs will be covered, including adaptive multi-fidelity surrogate modeling and local approximations. Numerical examples are presented to confirm that new approaches can obtain accurate posterior information with a limited number of forward simulations.

16. 杨家青 西安交通大学

题目: On recovery of the interface between the fluid and piezoelectric material

摘要: This talk is concerned with an inverse scattering problem for the interaction between the fluid and piezoelectric material. We show that the piezo-ceramic elastic body can be uniquely determined by the acoustic far-field pattern at a fixed frequency. The factorization method is then justified for the corresponding inverse interaction problem. Finally, we investigate the associated interior transmission eigenvalue problem. It is shown that there exist at most countable eigenvalues under some assumption on the parameters.

17. 张 磊 黑龙江大学

题目: Analysis and calculation for the scattering and inverse problems in complex backgrounds

摘要： In this talk, we mainly focus on the mathematical analysis and numerical calculation for the acoustic and electromagnetic wave scattering and inverse problems in complex backgrounds. Based on the boundary integral equation and variation method, we prove the composite scattering problem's well-posedness. We presented a numerical method for the boundary integral equation and analyzed its convergence. Furthermore, we show some results for the inverse problems. Finally, we will introduce our ongoing research work.

18. 张海文 中国科学院数学与系统科学研究院

题目： Near-field imaging of an unbounded elastic rough surface with a direct imaging method

摘要： This talk is concerned with the inverse scattering problem of time-harmonic elastic waves by an unbounded rigid rough surface. A direct imaging method is developed to reconstruct the unbounded rough surface from the elastic scattered near-field Cauchy data generated by point sources. A Helmholtz-Kirchhoff-type identity is derived and then used to provide a theoretical analysis of the direct imaging algorithm. Numerical experiments are presented to show that the direct imaging algorithm is fast, accurate and robust with respect to noise in the data.

19. 郑光辉 湖南大学

题目： Reaction coefficient inversion in nonlocal diffusion

摘要： Nonlocal diffusion model are widely applied in many fields, such as continuum mechanics, biology, jump process, graph theory, image analyses, machine learning, and phase transitions. In this talk, we discuss reaction coefficient inversion problem (RCIP) in three kinds of nonlocal diffusion model. The uniqueness theorems are established. Because of the ill-posedness, nonlinearity and singularity of RCIP in nonlocal diffusion. Some hybrid algorithms (such as variational regularization + Laplace approximation, variational Bayesian) are presented to recover the reaction coefficient, and capture the statistics information of the reaction coefficient. Finally, we give some numerical examples to show the effectiveness and reliability of the proposed algorithms.