Abstracts

Inverse Source Problems in Wave Propagation

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ABSTRACT

Recent progress on inverse source scattering problems in wave propagation will be discussed. The problems arise in diverse application areas including seismic imaging, nondestructive testing, materials design and analysis, and medical imaging. For the scattering problems, recent results on the boundary integral equation methods will be presented for elastic wave scattering. Concerning inverse source scattering, a unified stability analysis technique will be discussed for acoustic, electromagnetic, and elastic waves. Our new Lipschitz type stability results for the multiple frequency case overcome the ill-posedness of the fixed frequency inverse source scattering (ISS) problems. Uniqueness questions on ISS for the time-dependent elasticity problems will be addressed. Related ongoing research and open problems will be highlighted.

Qualitative versus Quantitative Approaches to Microwave-based Imaging Techniques for Medical Applications

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ABSTRACT

For now about forty years, the potential of microwaves as a new imaging modality has been increasingly investigated. Beyond its non-ionizing nature, microwaves were expected to provide specific information due to the known dependence of living tissue dielectric properties with respect to relevant bio-physical parameters such as composition, especially water content, temperature, blood flow-rate, etc. However, despite such expected advantages, microwave imaging has not yet gained its clinical recognition so far. Such a situation results to a large extent - but not only - from the complexity of microwave interactions with living tissues that exhibit large dielectric contrasts and, hence, are responsible for strong scattering mechanisms. After shortly reviewing the microwave-based imaging context and its timeline management by the microwave community, this presentation will explain the successive steps of the transition that occurred for moving from early single view projection to multiview tomography. A special focusing is dedicated to the comparison between qualitative and quantitative image reconstruction approaches, their general principles (inverse scattering, radar, holography) and requirements, their limitations and achievements of the day. For the sake of illustration, and due to their clinical relevance, different aspects of breast imaging will be more particularly considered, from screening to treatment monitoring, for which different microwave imaging systems providing either quantitative or qualitative images have been developed and engaged in (pre)clinical trials. Even if some time will be required to fully validate their performances and whatever the results of the current assessments, it may be expected that there is still probably some space for microwave systems to find a specific place among other existing modalities, whatever used either alone or in combination with these. To conclude, some propositions for filling this space are suggested. They will mainly consist of i) a better use of microwave technology, as already available for wireless communications or to come soon in the wake of expected 5G massive MIMO and IoT sensing networks technologies, ii) an anticipation of new generations of computers beyond Moore's law, and iii), last but not least, a mandatory reinforcement of partnerships with the medical community, including a come-back to basic biological investigations on microwaves-tissue interactions, from macroscopic down to cellular level.

Lens vs algorithm: optical imaging in the age of computers

SCOTT CARNEY

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ABSTRACT

Optical elements may be thought of as effecting a linear transformation of the optical field. Given access to the field, those same transformations, and many more, may be performed with a computer and so hardware may be replaced with software. I will mainly discuss the application of this idea in optical coherence tomography (OCT) where we have replaced complicated hardware with physics-based algorithms to produce a high-resolution 3-d imaging system with infinite depth of field in a compact form factor. I will give examples of the method in use in biological systems and results from a recent clinical trial in breast cancer.

Solving the inverse problem for optical imaging using diffusive light

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ABSTRACT

Near-infrared light can diffuse through soft biological tissues for a few centimeters. By measuring the diffusive transmission and diffusive reflection, it is possible to reconstruct maps of optical properties of the tissue under investigation. The reconstruction process, however, is generally related to a highly ill-posed inverse problem. In order to improve the image quality, a number of algorithms have been developed to optimize the optoes deployment, improve the accuracy, localization, and spatial resolution. Recently, a learned network is utilized to improve condition of the inversion, and remove the noise and artifacts at the same time.

The Reverse Time Migration Method for Inverse Scattering Problems

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ABSTRACT

The reverse time migration (RTM) or the closely related prestack depth migration methods are nowadays widely used in exploration geophysics. It is originated in the simple setting of the exploding reflector model. For imaging the complex medium in practical applications, the analysis of the migration method is usually based on the high frequency assumption, so that the geometric optics approximation can be used. We report our recent efforts in establishing new mathematical understanding of the RTM method without geometric optics assumption for inverse scattering problems. Our resolution analysis, which applies in both penetrable and non-penetrable obstacles with sound soft or impedance boundary condition on the boundary of the obstacle, implies that the RTM imaging functional always peaks on the boundary of the scatterers. This new mathematical understanding leads to several new direct imaging algorithms including: imaging for electromagnetic objects, imaging in half-space acoustics, imaging in closed waveguide, and imaging for scattering data without phase information. In this talk we will report the ideas of the RTM method and our recent result for imaging extended scatterers using the half-space elastic scattering data.

Solving Full-Wave Nonlinear Inverse Scattering Problems by Deep Learning Schemes

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ABSTRACT

The talk aims to solve a full-wave inverse scattering problem, which is a quantitative imaging problem, i.e., to reconstruct the permittivities of dielectric scatterers from the knowledge of measured scattering data. Scatterers are represented in pixel basis, which is a versatile approach since the value of permittivity of each pixel is an independent parameter. This talk proposes the convolution neural network (CNN) technique to solve full-wave nonlinear ISPs. It is well known that in order to make machine learning more powerful when solving a particular problem, researchers must have a deep understanding of the corresponding forward problem. The same applies to inverse scattering problems. The concept of induced current plays an essential role in the proposed CNN technique, which enables us to design architecture of learning machine such that unnecessary computational effort spent in learning wave physics is minimized or avoided. Several representative tests are carried out, and it is demonstrated that the proposed CNN scheme outperforms a brute-force application of CNN. The proposed deep learning inversion scheme is promising in providing quantitative images in real time.

Numerical Inversion of 3D geodesic X-ray Transform and its Application to Traveltime Tomography

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ABSTRACT

In this talk, we consider the inverse problem of determining an unknown function defined in three space dimensions from its geodesic X-ray transform. The standard X-ray transform is defined on the Euclidean metric and is given by the integration of a function along straight lines. The geodesic X-ray transform is the generalization of the standard X-ray transform in Riemannian manifolds and is defined by integration of a function along geodesics. This paper is motivated by Uhlmann and Vasy's theoretical reconstruction algorithm for geodesic X-ray transform and mathematical formulation for traveltime tomography to develop a novel numerical algorithm for the stated goal. Our numerical scheme is based on a Neumann series approximation and a layer stripping approach. In particular, we will first reconstruct the unknown function by using a convergent Neumann series for each small neighborhood near the boundary. Once the solution is constructed on a layer near the boundary, we repeat the same procedure for the next layer, and continue this process until the unknown function is recovered on the whole domain. One main advantage of our approach is that the reconstruction is localized, and is therefore very efficient, compared with other global approaches for which the reconstructions are performed on the whole domain. We illustrate the performance of our method by showing some test cases including the Marmousi model. Finally, we apply this method to a travel time tomography in 3D, in which the inversion of the geodesic X-ray transform is one important step, and present several numerical results to validate the scheme.

This work is partially supported by the Hong Kong RGC General Research Fund (Project: 14301314).

Imaging through Random Media by Speckle Intensity Correlations

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ABSTRACT

When waves propagate through random media the energy is transferred to the incoherent wave part by scattering. The wave intensity then forms a random speckle pattern seemingly without much useful information. However, a number of recent physical experiments show that it is possible to extract useful information from this speckle pattern and to image an object buried in a random medium. Here we present the mathematical analysis that explains the quite stunning performance of speckle imaging. Our analysis identifies a scaling regime where these schemes work well. This regime is the white-noise paraxial regime, which leads to the Ito-Schrodinger model for the wave amplitude. Our results conform with the sophisticated physical intuition that has motivated these schemes, but give a more detailed characterization of the performance. The analysis gives a description of (i) the information that can be extracted and with what resolution (ii) the statistical stability or signal-to-noise ratio with which the information can be extracted.

Time Reversal Features and Applications of Space-Time Discrete Electromagnetic Models

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ABSTRACT

Computational models of electromagnetic wave propagation empower us to commute freely between the past and the future, and thus to interchange cause and effect in the virtual realm. Traditionally one would like the wave properties of these models to closely match those of the wave equation. Hence, the discretization must be typically ten times finer than the shortest spatial wavelength, and the achievable spatial resolution of source reconstruction, or Abbe limit, will be about half that minimum wavelength, i.e. five discretization steps. This would require considerable computational resources, but it would be necessary if the computational model were used to invert a measured or an analytical field response. On the other hand, space-time discrete models such as FDTD (Finite Difference Time Domain) or TLM (Transmission Line Matrix) models, can propagate high spatial frequencies that would be evanescent in continuous models. This implies that sources can be resolved with the spatial and temporal resolution of the discrete model, which is five times the Abbe limit. However, this property is only useful as long as both the forward and the inverse processes are modeled in the same discrete environment. This can indeed be exploited in the electromagnetic synthesis of structures. In this presentation the pertinent wave properties of the TLM model and its suitability for reconstructing both active and induced sources with mesh resolution will be discussed. Finally, a typical procedure for synthesizing obstacles in waveguides from S-parameter specifications will be presented.

A man-portable MRI imager & the non-linear gradient image reconstruction

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ABSTRACT

A portable magnetic resonance imaging (MRI) imager may help this medical imaging modality to reach out areas that are remote or/and hard to access, and situations that the environment is dynamic, for example, in an ambulance. This talk reports the progress of the development of a man-portable MRI imager in Singapore University of Technology and Design. The main idea is to use permanent magnet for supplying static magnetic field thus getting rid of the need of a bulky superconducting magnet. The field from a permanent magnet array is not homogeneous and this inhomogeneity is used for imaging without gradient coils. In the talk, the design and implementation of the hardware, including the magnet (that supplies B0), radiofrequency (RF) coils (that supplies B1), CONSOLE (RF control circuit), will be presented. On top of the hardware, the progress on the image reconstruction that makes sure of the inhomogeneity of the static magnetic field will be shared.

Convexification of Coefficient Inverse Problems

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ABSTRACT

Conventional least squares cost functionals for Coefficient Inverse Problems are non-convex. The non convexity causes the phenomenon of multiple local minima and ravines. This phenomenon plagues the issue of numerical methods for these problems. We present a new concept: construction of globally strictly convex cost functionals for a broad class of Coefficient Inverse Problems. The Carleman Weight Function is the key element of such a functional. Global convergence of the gradient projection method to the correct solution is proved. Numerical results for both computationally simulated and experimental data will be presented. If time will allow, we will also present a new idea connecting x-ray tomography with the quasireversibility method and a Carleman estimate.

Computational imaging of micro-structured media at small scale - from one-shot first-order solutions to full-wave iterative ones

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ABSTRACT

The talk will focus onto computational imaging of micro-structured systems as recently illustrated within a pluri-disciplinary, pluri-institute framework of investigation, e.g.,[1], [2], results of works in progress being also proposed opening towards possibly new paths. The question behind the scene is on how to achieve meaningful localization —i.e., with enhancement of resolution or, even better, super-resolution vs. the wavelength of operation [3], [4]— of (supposedly simple) defects and/or radiators when those are to be identified within a micro-structured system of circular cylindrical dielectric rods or metal wires distributed in regular fashion in space from properly collected time-harmonic scattered or radiated fields at the exterior of the investigated domain—data could be frequency-diverse also.

The main application (with most of the authors and colleagues' publications available on it) is the testing of fibered laminates: assume a planar polymer layer containing an infinite set of circular cylindrical graphite or glass rod-like fibers, ideal line sources and receivers being set above the layer in a reflection mode, one or several of the rods possibly missing (other types of defects could be envisaged as well). Here, both one-shot MUSIC and iterative sparsity-constrained source imaging, at a single frequency of operation, will be considered. Some emphasis will be on what happens with noisy/incomplete data, and attention duly given to the situation in which one goes closer and closer to resonance (interrogation at a wavelength tending to be about the inter-element distance, the radius of the rods, and the thickness of the layer) for which first-order MUSIC-like methods are expected to fail while the full-wave solution might suffer from strong ill-conditioning due to inaccurate reproduction of the wave phenomenon itself (in particular, fields around each rod areplayed with as truncated cylindrical modes expansions) during the inversion process.

This will be completed by illustrative results acquired for a set of similar rods yet now finitely numbered and distributed within a square domain in free space, and observed from all around (a line source inside an intact system of rods is to be localized, or a line source may illuminate a damaged system and any missing rod found). Now, time-reversal (provided broad-band transient data) and sparsity-constrained imaging will be employed, in both TE and TM polarizations (the behavior may drastically differ), and discussed as solution tools.

To complete, one will tackle a 3-D full-wave configuration supported by laboratory experiments in an anechoic chamber: short monopole wire antennas apart by a small fraction of operation wavelength are inserted within a finite set of regularly distributed, shorter thin metal wires also apart similarly, and the monopole that radiates must be found from far field patterns (those exhibit sharp changes vs. the position of the radiator in the frequency band associated to resonances).

Time permitting, how to shift from solution methods as seen in the above to supervised learning involving feature analysis and regression will be pointed out.

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The contribution of Changyou Li, NPU, Xi'an, on models of fibered laminates, is acknowledged.

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Feasibility Study of Multi-physics Imaging for Human Thorax

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ABSTRACT

Respiration and circulation are the most important functions for maintaining life. The lungs and heart, both central organs that perform respiratory and circulatory functions, are located in the thorax. The thorax can be considered as inhomogeneous medium containing solid, fluid, and gas. Deviation of their content and distribution from normal values reflect different pathological conditions in the lungs and/or circulatory system, which are often life-threatening. Therefore, real-time monitoring of abnormalities in the distribution of fluids and gases in the human thorax is crucial for the treatment of critically ill patients.

The best imaging methods for monitoring content and distribution of fluid and gas in the thorax should be non-invasive, radiation-free, and suitable for real-time, long-term dynamic monitoring at the bedside. In this work, we will study the feasibility of using multi-physics measured data including electrical impedance tomography (EIT), microwave tomography, and low frequency ultrasound tomography to achieve this goal. These three methods have different sensitivity to fluid and gas. Nonlinear inversion algorithms can be applied to reconstruct the fluid and gas distribution from the data measured around human thorax. Integrating these methods together may help to reconstruct the fluid and gas content and distribution in human thorax and provide a bedside real-time monitoring methodology to help patients in intensive care units.

Direct and Inverse Scattering Problems for Elastic Waves

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ABSTRACT

The scattering problems for elastic waves have received great attention for their significant applications in diverse scientific areas such as geophysics and seismology. In this talk, I shall present our recent studies on analysis and computation for some direct and inverse elastic scattering problems, which include the acoustic-elastic interaction problems, the inverse obstacle and source scattering problems, and the time-domain scattering problems.

Mitigating the Nonconvexity of the Seismic Inverse Scattering Problem

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ABSTRACT

Seismic full waveform inversion (FWI) has the great potential to retrieve high fidelity subsurface models. However, FWI is highly nonlinear and non convex at high frequencies. To speed up the convergence and mitigate the nonconvexity, we adapt the gradient sampling algorithm (GSA) for the computational intensive problem of FWI. Numerical examples demonstrate that the adapted GSA results in more reliable inversion results than the conventional FWI when starting from a very crude initial model.

Compressive Processing in Inverse Scattering Problems: State-of-the-Art, Current Advances, and Future Trends

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ABSTRACT

The widely known Shannon/Nyquist theorem relates the number of samples required to reliably retrieve a "signal" to its (spatial and temporal) bandwidth. This fundamental criterion yields to both theoretical and experimental constraints in several Electromagnetic Engineering applications. Indeed, there is a relation between the number of measurements/data (complexity of the acquisition/processing), the degrees of freedom of the field/signal (temporal/spatial bandwidth), and the retrievable information regarding the phenomena at hand (e.g., dielectric features of an unknown object, presence/position of damages in an array, location of an unknown incoming signal).

The new paradigm of Compressive Processing (*CP*) is completely revisiting these concepts by distinguishing the "informative content" of signals from their bandwidth. Indeed, *CP* theory asserts that one can recover certain signal/phenomena exactly from far fewer measurements than it is indicated by Nyquist sampling rate. To achieve this goal, *CP* relies on the fact that many natural phenomena are sparse (i.e., they can be represented by few non-zero coefficients in suitable expansion bases) and on the use of a-periodic sampling strategies, which can guarantee, under suitable conditions, a perfect recovery of the information content of the signal.

Dealing with inverse scattering problems, *CP* can efficiently solve linear/nonlinear inverse scattering problems, given a limited set of measurements of the scattered field [1] starting from the knowledge of some *a-priori* information on the class of the unknown scatterers. Within this context, two different problems arise: the problem of sampling (*"compressive sampling" - CSA*) the data with the minimum number of samples, and the problem of sensing (*"compressive sensing" - CSE*) the unknown signal starting from the known measured samples.

Being the Restricted Isometry Property (*RIP*) of the observation matrix a necessary condition for using standard *CSE*-solvers, in the last years Bayesian Compressive Sensing (*BCS*)-based techniques, thanks to their possibility to overcome the RIP condition issue, have been effectively applied to microwave imaging problems [1]-[8], formulating the sensing problem as a linear one, by means of contrast-source formulations [2, 3], or Born-I [4] and Rytov [5] approximations. The CS intrinsic sparsity requirement of the unknowns has been exploited as *a-priori* information by representing different class of targets in different domains, (e.g. in the gradient domain [6]) with different basis functions [7, 8].

As for the *CSA* problem, the possibility to reduce the number of measurements with respect to standard "Nyquist" limits, assuring a well-posed/well-conditioned problem, is still an open task. Unfortunately, no analytic and efficient methods exist to exactly compute the Restricted Isometry Constant (*RIC*) which is necessary for estimating the well-posedness of the problem [9]. Anyway, recent advances in information theory have enabled to efficiently deduce reliable upper bounds of the *RIC* [9]. The *RIC* estimation methods can thus be exploited by combining them with optimization techniques with the aim of optimize the number and position of the measurement probes of the imaging system.

The aim of this talk is to discuss *CP* paradigm in a broad sense (i.e., *CSA* and *CSE* as two faces of the same coin instead of separate tasks) starting from its fundamentals and to illustrate its features and potentialities in inverse scattering & imaging methods, also envisaging possible future trends in CS.

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Fault Detection in Acoustic and Electromagnetic Waveguide Channels with Applications to Pipeline and Transmission Line Networks

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ABSTRACT

Investigation of inverse scattering in 1-dimension (1D) has a long history and a variety of techniques have been developed for providing 1D reconstructions of parameters such as impedance. These results have been used in a wide variety of applications. However new applications and requirements are making further demands on these approaches. In the research reported here we consider new applications in urban water supply systems (UWSS) and electrical transmission line networks. UWSS systems support the lives of billions of people and therefore their safe and reliable operation is critical. For example contamination or interference with UWSS can have serious health and security implications, while pipe failures can disrupt lives, businesses and cause damaging flooding. However current methods for sensing, collecting and processing data in pipeline networks to address these issues are not adequate. One possible approach to acquiring pipeline data is through the development of acoustic systems such as sonar that operate inside pipelines to detect pipeline faults such as leaks and blockages. Similarly detecting faults in cable and optical networks is becoming increasingly important as the world becomes more interconnected and electrified. Cable and optical networks are the distribution backbone of signals and electricity for a plethora of services including those in buildings, transport systems, automobiles and airplanes where they are a fundamental subsystem. Both of these applications can be formulated as 1D inverse scattering problems in which multiple parameters such as blockages and leaks or impedance and shunt distributed parameters need to estimated in lossy waveguide channels. In the research reported here we describe straightforward methods for estimating multiple parameters in these networks and their performance in experimental settings. In addition we illustrate open problems that existing techniques cannot handle in these two applications.

Inverse Problem for Anisotropic Elasticity System

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ABSTRACT

As a mathematical model for vibroseis exploration technique in reflection seismology, we study the uniqueness of recovering piecewise analytic density and stiffness tensors of a three-dimensional domain from the local dynamical Neumann-to-Dirichlet map. We give global uniqueness results if the medium is transversely isotropic with known axis of symmetry or orthorhombic with known symmetry planes on each subdomain. We also obtain uniqueness of a fully anisotropic stiffness tensor, assuming that it is piecewise constant and that the interfaces which separate the subdomains have curved portions. The domain partition need not to be known. More precisely, we show that a domain partition consisting of subanalytic sets is simultaneously uniquely determined.

Microwave Near-field Imaging in Real Time

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ABSTRACT

In the last decade, we have witnessed dramatic decrease in the price and size of microwave electronics along with the advent of the radio-on-a-chip (RoC), the software-defined radio (SDR), and the single-chip radars. This led to a rapid recent growth in microwave and radar imaging and detection, which define the future growth of wireless technology. We will discuss the challenges and the methodologies of microwave imaging in the case of near-field measurements. We will focus on fast reconstruction methods that yield results in real time. We will start with a brief summary of the used electromagnetic models. We will then discuss briefly the inner workings of two prominent imaging methods, namely, microwave holography and synthetic focusing.

Qualitative radar imaging under randomized field illumination

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ABSTRACT

Recently, microwave imaging under pseudo random field illuminations have attracted many interests. In this work, we theoretically analyzed and experimentally implemented a radar imaging system that can be customized on the demands of the desired object size and imaging resolution. Based on completely random illuminations generated by the minimum number of antenna elements, an analytical equation can be used to reconstruct the object almost in real time. The simple-structured and cost-effective imaging system can be implemented in microwave, millimeter wave and even sub-THz frequency bands, having promising potentials in diverse microwave imaging applications.

Inverse Transport with Finite Number of Internal Data Sets

Kui Ren

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ABSTRACT

I will review some recent developments in theoretical and computational analysis of inverse coefficient problems to the radiative transport equation and systems with finite number of internal data sets, as well as applications of such problems in imaging.

Unique continuation and inverse boundary problems for the Schrödinger equation with singular coefficients

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ABSTRACT

In this talk I would like to discuss the (quantitative) unique continuation property for solutions to the Schrödinger equation with singular coefficients and related inverse boundary problems. An important question is to investigate how the vanishing order of the solution depends on the coefficients. The vanishing order is a quantitative form of the strong unique continuation property for the solution. It has been known that the unique continuation property is closely related to the uniqueness of the inverse boundary value problem. Here we consider coefficients belonging to some Lebesgue spaces. We are especially interested in the borderline case where the unique continuation property holds.

Some inverse problems in the upstream oil and gas industry

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ABSTRACT

There are many applications pertaining to solving inverse problems in the upstream oil and gas industry. This presentation illustrates some measurement methods for imaging important physical parameters (e.g. seismic velocity, electrical resistivity) that are of key values in hydrocarbon exploration, reservoir monitoring, and oil-gas production monitoring.

Seismic (traveltime) tomography and depth imaging are widely used for hydrocarbon exploration at large (kilometres) reservoir scale. Cross-borehole seismic surveys are also applied at a smaller (inter-well) scale. Seismic waves are reflected or refracted at subsurface boundaries between layers of different properties. Processing (by solving appropriate inverse problem) recorded seismic waves returning from the subsurface to receivers (e.g. geophones, hydrophones) located at surface (or borehole) allows inference of velocities and lithological composition of subsurface layers, and construction of a geological model of the reservoir. Important attributes derived from inverse-problem solution, such as spatial distributions of p-wave and s-wave velocities, or of their ratio, can be used to determine reservoir depth, extent and heterogeneity, as well as fluid content, rock-mechanical properties, pore pressure, progress of reservoir-sweep by enhanced oil-recovery (EOR) revealed by time-lapse (space-time) seismic survey. Hydraulically induced fractures can also be monitored using borehole seismic.

Cross-well electromagnetic (induction) tomography for reservoir monitoring can be achieved by solving related resistivity-imaging inverse problem. Induction measurements respond primarily to electrical resistivity. Cross-well resistivity imaging (covering an inter-well scale less than 1-km) is used to distinguish the electrical contrast between resistive-oil and conductive-brine bearing formations. Inter-well resistivity data are useful for mapping variations in reservoir properties during, for example, waterflood and steam-flood processes.

Complex oil-gas-water multiphase flows often occur in hydrocarbon production pipelines, and the accurate measurement of their flow rates over a wide range of flow regimes is a continuing challenge for the oil and gas industry. Taking advantage of the advancement in medical computed tomography, industrial process tomography has been identified as having the potential for measuring dynamic multiphase flow since 1990s. The basic concept is to mathematically reconstruct the phase holdup and phase velocity profiles at a sufficient spatial and temporal resolution from appropriate multiple measurements made at a pipe's periphery (i.e. an inverse problem). The individual-phase volumetric flow rates are then derived by appropriately integrating phase holdup and phase velocity profiles over the pipe cross-section. In this presentation, some results from electrical tomography for oil/gas/water multiphase flow imaging and measurement will be illustrated.

Strong Interaction between Plasmonic Spheres

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ABSTRACT

Confining light into a nanoscale region is quite challenging due to the diffraction limit. To overcome this difficulty, the plasmonic (metallic) nanoparticles and their optical resonances have been extensively studied and utilized. Among various plasmonic structures, the system of spheres is of the fundamental importance. When the spheres are nearly touching, the broadband light concentration occurs due to their strong interaction. This phenomenon has a potential application in nanophotonics, biosensing and spectroscopy. However, the strong interaction is quite challenging to understand both analytically and numerically. There are two approaches for the electromagnetic interaction between the spheres: (i) transformation optics and (ii) the image charge method. Unfortunately, neither is entirely satisfactory in the case of the plasmonic spheres. In our recent work, we clarify the connection between these two approaches and then completely solve the spheres problem. We discuss how this interesting connection can provide a deep understanding of the strong plasmonic interaction.

Mathematical Studies of Anomalous Scattering by Subwavelength Slit Structures

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ABSTRACT

Since the discovery of the extraordinary optical transmission through nanohole arrays in metallic films by Ebbesen, a wealth of research has been sparked in the experimental and theoretical investigation of localized electromagnetic field enhancement in subwavelength nanostructures. This remarkable phenomenon can lead to potentially significant applications in near-field imaging, bio-sensing, etc. However, there has been a long debate on the interpretation of the enhancement effect since Ebbesen's work. In addition, a quantitative analysis of the field enhancement in subwavelength structures is still widely open. In this talk, using two-dimensional slits as a prototype, I will present mathematical studies of the field enhancement in the subwavlength structures. Based upon the layer potential technique, asymptotic analysis and homogenization theory, the enhancement mechanisms for both the single slit and an array of slits are studied quantitatively.

Instability of an inverse problem for the stationary radiative transport near the diffusion limit

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ABSTRACT

In this work, we study the instability of an inverse problem of radiative transport equation with angularly averaged measurement near the diffusion limit, i.e. the normalized mean free path (the Knudsen number) is $0 < \epsilon \ll 1$. We show the transition of stability by establishing the balance of two different regimes depending on the relative sizes of ϵ and the perturbation in measurements. When ϵ is sufficiently small, we obtain exponential instability, which stands for the diffusive regime, and otherwise we obtain Hölder instability instead, which stands for the transport regime.

Implementation of a new type of contraction integral equation for highly nonlinear 3-D inverse scattering problems

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ABSTRACT

Inverse scattering problems (ISPs) in electromagnetics and acoustics are of great interest in industries due to its important applications in various areas, such as geophysical survey, non-destructive testing, bio-medical imaging, etc. On the other hand, they are also quite important due to the representative difficulties in solving a large group of inverse problems concerning waves and fields, and thus researchers in mathematics, physics, and engineering societies have devoted efforts of decades, trying to improve efficiencies and accuracies of the numerical solvers [1, 2]. As most of the practical problems are three-dimensional (3-D) ones, which incurs much more computational burdens onto the CPU and memory compared with those in 2-D cases, they are often more difficult to solve due to the data deficiency (measurement aperture usually covers a small solid angle), and therefore stronger ill-posedness and non-linearity. Great efforts have been paid to tackle these demanding problems, for instance [3, 4, 5].

Recently, a new contraction integral equation for inversion (CIE-I) has been proposed to tackle the 2-D highly nonlinear ISPs in [6], by transforming the usually employed Lippmann-Schwinger integral equation (LSIE) into a new form with a modified medium contrast via a contraction mapping, $R = \beta\chi/(\beta\chi + 1)$, where R is the modified contrast, χ is the original medium contrast, and β is the auxiliary parameter to control the mapping. With the CIE-I, the multiple scattering effects, the physical origin of the nonlinear effects of the ISPs, are substantially suppressed in estimating the modified contrast, without compromising physical modeling (as done in most of the linearized models). Doing so, the inversion solvers with CIE-I have much better abilities to cope with the strong non-linearity in ISPs.

In this talk, the new CIE-I will be implemented in tackling the 3-D ISPs. As in the 3-D cases, the computational burdens are quite high even using the CSI type optimization scheme [3, 5], without solving any direct scattering problems. Through numerical examples, we will see that the convergence of the optimization is much faster compared with the case using the LSIE. Also, when handling the highly nonlinear problems, usually with higher contrast and/or larger dimensions (in terms of wavelengths), the performance of the inversions with CIE-I is much better than those with LSIE, as the latter usually converge to local minima that may be far away from the wanted solution. In addition, we will further investigate the possibility of accelerating the convergence of the optimization by relaxing the contraction mapping, i.e., we will use different contraction mapping in different updates of the unknowns. With these strategies, we hope that the efficiency of the inversion solver for 3-D ISPs will be effectively increased.

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Direct Sampling Methods for General Inverse Problems

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ABSTRACT

In this talk we review the recent developments in direct sampling methods for wave-type and non-wave-type inverse problems. Some general principles and justifications are discussed for the choices of several key ingredients of the direct sampling methods.