09w5017: Mathematical Methods in Emerging Modalities of Medical Imaging
Oct 25 - Oct 30, 2009
Abstracts of presentations

1. **Simon Arridge**, Department of Medical Physics and BioEngineering, University College London, UK

   Title: Quantitative Reconstruction in PhotoAcoustic Tomography

   Abstract:

   PhotoAcoustic Tomography (PAT) uses light to create sound sources (by heat generated on optical absorption) and image reconstruction consists of an inverse acoustic source reconstruction, which can be done using conventional ultrasound methods. In order to quantify the optical properties underlying the sound generation it is necessary to couple models for optical and acoustic propagation. In this talk I present some of our recent work on this problem, utilizing a non-linear algorithm for recovering optical absorption coefficient. **Joint work with Ben Cox, Paul Beard**

2. **Guillaume Bal**, Columbia University

   Title: Inverse transport and inverse diffusion theories for photoacoustics

   Abstract:

   Photoacoustic tomography consists of two steps. In the first step, the spatial structure of the amount of deposited radiation is reconstructed inside a domain of interest by solving an inverse wave problem. In a second step, the optical properties in the domain are reconstructed from the now known deposited radiation. We consider the second step and show what can or cannot be reconstructed in the optical parameters for two regimes of propagation of radiation: transport (**joint work with Alexandre Jollivet and Vincent Jugnon**) and diffusion (**joint work with Gunther Uhlmann**).

3. **Wolfgang Bangerth**, Math. Dept., Texas A&M University

   Title: Reconstructions in ultrasound modulated optical tomography

   Abstract:

We describe a mathematical model for ultrasound modulated optical tomography and present a simple reconstruction algorithm and numerical simulations for this model. The computational results show that stable reconstruction of sharp features of the absorption coefficient is possible. A formal linearization of the model leads to an equation with a Fredholm operator, which explains the stability observed in our numerical experiments. **Joint work with Moritz Allmaras and Peter Kuchment.**

4. **Peter Burgholzer**, Upper Austrian Research

   Title: Image Reconstruction in Photoacoustic Tomography taking acoustic attenuation into account

   Abstract:

   Photoacoustic Imaging (also known as thermoacoustic or optoacoustic imaging) is a novel imaging method which combines the advantages of Diffuse Optical Imaging (high contrast) and Ultrasonic Imaging (high spatial resolution). A short laser pulse excites the sample. The absorbed energy causes a thermoelastic expansion and thereby launches a broadband ultrasonic wave (photoacoustic signal). This way one can measure the optical contrast of a sample with ultrasonic resolution. Optical detectors can provide a high bandwidth up to several 100 MHz. Using these detectors the resolution is often limited by the acoustic attenuation in the sample itself, because attenuation increases with higher frequencies. Compensation of this frequency-dependent attenuation is an ill-posed problem and is limited by the thermodynamic fluctuation of the measured pressure around its mean value. These fluctuations are closely related to the dissipation caused by acoustic attenuation (fluctuation dissipation theorem) and therefore a theoretical resolution limit for the maximal compensation of photoacoustic attenuation can be estimated.

5. **Scott Carney**, University of Illinois Urbana-Champaign

   Title: Deconstructing the Born series

   Abstract:

   In this work a new method to directly obtain from experiment the separate orders of the scattered fields from the exact scattered field is proposed. The approach is generic in that it applies to any system for which a solution may be cast as a Liouville-Neumann series. The method is simulated and shown to reduce multiple-scatter artifacts in linearized inverse scattering. The method has potential to also be used in so-called super-resolution problems.

6. **Mathias Fink**, Univ. Paris 7

   Title: "Multi-Wave imaging and super-resolution".

7. **David Isaacson**, Rensselaer Polytechnic Institute

   Title: Problems in the diagnosis and treatment of breast cancer.

   Abstract:

   Depending on time and interest I will present problems arising in the diagnosis and treatment of breast cancer. The problems include:

   - How to improve the diagnosis of breast cancer by electrical impedance spectroscopy.
   - How the ordering of the administration of drugs used in the chemotherapy of breast cancer can make a significant difference in the outcome.
   - How the number of Her2 receptors on breast cancer cells affects their proliferation rate.

8. **Alexander Katsevich**, Math. Dept., University of Central Florida

   Title: An accurate approximate algorithm for motion compensation in two-dimensional tomography

   Abstract:

   We propose an approximate inversion formula for motion compensation in tomography. Let E denote the operator, which corresponds to the error term of the inversion formula. It is proven that $E : H_m \to H_{m+1}$ is bounded, thus the error term is one order smoother than the original function f in the scale of Sobolev spaces. It is proven also that if the motion map approaches the identity map, then the norm of E approaches zero. The formula can be easily implemented numerically. Results of numerical experiments in the fan-beam case demonstrate good image quality even when motion is relatively strong.

9. **Peter Kuchment**, Math. Dept., Texas A&M University

   Title: Can one hear the heat of a body? Survey of the mathematics of Thermo- and Photo-acoustic tomography

   Abstract:

   The talk will survey main mathematical results and open problems of thermoacoustic tomography. **Joint with David Finch and Leonid Kunyansky.**

10. **Leonid Kunyansky**, Math. Dept, Univ. or Arizona

    Title: Synthetic focusing in Acousto-Electric Impedance Tomography

    Abstract:

    Electrical Impedance Tomography (EIT) is known as a harmless and cheap imaging modality; unfortunately, it is very unstable. To stabilize the reconstruction one can scan the object with an acoustic wave focused to a point — such a technique is called Acoustic-Electric Impedance Tomography (AEIT). We will discuss the theoretical and numerical details of this technique, and demonstrate reconstructions obtained from simulated data — all of which show vast improvement in stability and image resolution as compared to EIT. We also address the issue of a perfect focusing of acoustic waves which is almost impossible to achieve in practice. We propose an alternative approach where the medium is perturbed by a spherical acoustic front or by a series of spherical monochromatic waves. Then the desired but impossible to obtain electrical measurements (that would correspond to perfectly focused perturbations) are synthesized from measurements that are made using realistic acoustic perturbations. Our numerical experiments confirm the efficiency of such "synthetic" focusing. **Joint work with P.Kuchment.**

11. **Rick Lawrence**, National Center for Microscopy and Imaging Research

    Title: Advances in Large Field and High Resolution Electron Tomography

    Abstract:

    In recent years the biological electron microscopy community has adapted technical improvements in instrumentation, data collection modes and large format digital image detectors. For example images on the order of 8K X 8K pixels are commonplace, and multiple detectors and montaging techniques make series of billion-pixel images achievable without extraordinary effort. This flood of image data plays an important role in determining the three-dimensional structure and function of cells and sub-cellular organelles. Structure may be elucidated across a wide range of spatial scales, ranging from that of neurons in the brain, for example, down to the scale of proteins and protein complexes. Electron microscope (EM) tomography presents a number of special problems. The imagery is low contrast and noisy with limited sampling of projection directions; sample warping and the curvilinearity of electron trajectories make classical techniques of x-ray tomography problematic; and the volume and scale of the data make automated preprocessing and image segmentation necessary. The need for solution of these problems has spurred the introduction of new techniques into EM tomography. Progress in all aspects of EM tomography requires deeper mathematical understanding. For example, the presence of geometric nonlinearities in the basic ray transform requires that the inversion problem be treated in terms of Fourier integral operators rather than Fourier transforms.

12. **Armando Manduca**, Mayo Clinic

    Title: Magnetic Resonance Elastography: Overview and Open Problems

    Abstract:

    MR elastography can quantitatively and non-invasively measure full 3D vector displacement data from propagating acoustic waves in vivo. From these data, inversion algorithms can calculate biomechanical tissue properties such as stiffness, viscosity, and anisotropy. An overview of MRE and inversion techniques will be presented, along with a discussion of open problems and issues. Preliminary studies indicate that the technique has substantial potential as a diagnostic tool.

13. **Vadim A. Markel**, University of Pennsylvania

    Title: Inverse radiative transport with the method of rotated reference frames

    Abstract:

The method of rotated reference frames was developed by us in the past five years. In particular, the method allows one to obtain the plane-wave decomposition of the Green's function for the radiative transport equation (RTE) in the slab geometry. This expansion can be efficiently used to solve the linearized inverse problem for the RTE. I will talk about the mathematical formulation of the method and its application to inverse problems and imaging. Examples of image reconstruction with both simulated and experimental data will be presented.

14. **Joyce McLaughlin**, Rensselaer Polytechnic Institute

Title: Biomechanical Imaging: Viscoelastic Models, Algorithms, Reconstructions; Application to Breast, Prostate and Brain

Abstract:

Biomechanical imaging is a promising new technology that enables monitoring of and predicting disease progression and the identification of cancerous and fibrotic tissue. The dynamic data that is input for our work is movies of propagating or harmonic waves; the movies are created from sets of MR or sets of ultrasound data that is acquired while the tissue is moving in response to a pulse or an oscillating force. The main characteristics of the movies are: either (1) there is a wave propagating with a front; or (2) there is a traveling wave created by two sources oscillating at different but nearly the same frequencies; or (3) there is multifrequency harmonic oscillation.

We will briefly show some of our recent work in cancer identification created from data with the characteristics (1) or (2) above. The remaining talk will concentrate on the mathematical model, algorithms and reconstructions for movie data acquired when the tissue is undergoing response to a single or multifrequency harmonic oscillation. We discuss viscoelastic and elastic models, our current choice for viscoelastic model and its properties. We discuss approximations to the mathematical model, estimates of the error made by the approximation, the algorithms inspired by the full model and the approximate model and their stability and accuracy properties, why some biomechanical parameters cannot be reliably recovered, and current questions about biomechanical parameters that inspire our work. We present images created by our algorithms both from synthetic, in vivo and in vitro data.

15. **Shari Moskow**, Drexel University

    Title: The Inverse Born Series for Diffuse Waves.

    Abstract:

    We consider the inverse scattering problem for diffuse waves. We characterize the convergence, stability and approximation error of the solution to this problem which derives from inversion of the Born series. Numerical simulations for spherically symmetric absorbing media in two and three dimensions will be presented. We then discuss the possible use of the inverse Born series approach for other problems such as propagating scalar waves and Electrical Impedance Tomography. **Joint with John C. Schotland**.

16. **Adrian I. Nachman**, University of Toronto

    Title: Current Density Impedance Imaging

    Abstract:

    This tutorial talk will present a newly emerging method for imaging the electric conductivity of tissue from interior measurements of current density. We will first review how the current density can be determined inside an object using a Magnetic Resonance Imager (a technique invented by M.Joy's group). If two currents are available, we give an analytic formula for calculating the conductivity, and show experimental validation of this method (**joint work with K. Hasanov, W. Ma, and M. Joy**). Much of the talk will then address the problem of reconstructing the conductivity from knowledge of just the magnitude of one current in the interior. This is **joint work with A. Tamasan and A. Timonov**. We show that the corresponding equipotential surfaces are minimal surfaces in a conformal metric determined by the given data, prove identifiability and give numerical reconstructions. We hope that the discovery that it suffices to measure just the magnitude of one current may lead to novel physical approaches to obtain this data directly.

17. **Victor Palamodov**, Tel Aviv University

    Title: Reconstruction in Doppler tomography

    Abstract:

Integrals of a vector field model measurements in tomographic imaging of liquid or gas flows, tumor detection, optics and plasma physics etc. These tomographic modalities are developing since seventies. In this context, the data of longitudinal line integrals of a vector field (or a 1-differential form f) form is called the Doppler transform according to the Doppler shift law. The reconstruction problem for the Doppler transform has some peculiarities: the object of reconstruction is a more complicated than a function and the transform is invariant to the gauge transformation f -¿ f+dh, since all line integrals vanish for any exact form (irrotational part of the field). Therefore only reconstruction of the differential df is possible. However by the Helmholtz theorem, the solenoidal part of the form f can be uniquely reconstructed from data of the df. In 2D case the reconstruction problem is immediately reduced to inversion of the Radon transform. In 3D case the complete 4D-data of line integrals are redundant. The problem is to find which (possibly small) 3D subvarieties in the data space are sufficient for a reconstruction of df. We discuss some known results and show that the form df can be recovered from ray integrals of f whose acquisition geometry is roughly the same as for optimal reconstruction of a scalar function. This method can extended for differential forms of arbitrary degree.

18. **Eric Todd Quinto**, Tufts University

    Title: Electron Microscope Tomography

    Abstract:

    We will discuss electron microscope tomography (ET) from a mathematical perspective and describe algorithms we are developing as well as the microlocal analysis behind them. For small field ET, one can assume the electrons travel over lines, and we will present reconstructions **with Ozan Öktem and Ulf Skoglund** for this model. For larger field ET, the electrons travel over curvilinear paths (you will hear about this in Albert Lawrence's talk). We will describe a new mathematical model for this problem using a Radon transform over curvilinear paths. We will give the microlocal analysis of this transform, and provide reconstructions from an **algorithm Hans Rullgard and I are developing**.

19. **Eric Ritman**, Mayo Clinic College of Medicine

Title: Micro-Tomographic Imaging of Coherent X-ray Scatter using a Polycapillary X-Ray Optic Imaging System and Multi-Energy X-Ray Detection

Abstract:

Coherent scatter of x-ray can convey information about the chemical bonds in the material being irradiated when the length of chemical bonds is of the order of an x-ray wave length. Consequently, the scatter can be used to discriminate certain chemical compounds (with similar atomic content) that have very similar x-ray attenuation coefficients. The scatter intensity can either be recorded as a function of angle (θ) from an illuminating, monochromatic, x-ray beam ($q = (1/\lambda)\sin(\theta/2)$ or can be recorded by an energy-binning detector at one angle to a bremsstrahlung x-ray beam ($q = (E/12.3)\sin(\theta/2)$). Both methods provide a scatter intensity profile (q=momentum transfer function) that is characteristic for the illuminated material, but its intensity must be corrected for attenuation of the illuminating beam, as well as of the scattered beam, hence a conventional CT image is needed to provide the attenuation map. There are several modes of illumination and scatter recording that trade off signal-to-noise, speed of the data collection and need for Radon-type tomographic reconstruction from line integrals of the scatter. If a collimator is used then line or sheet illumination can provide scatter data from known points within the 3D structure so that no tomographic reconstruction is needed. If a non collimated detector array is used, or a volume is illuminated and scatter recorded via a collimator, then line integrals are recorded and the object has to be rotated in order to provide the data needed for Radon-type tomographic reconstruction. We have used polycapillary x-ray optics and energy selective imaging to generate tomographic image data that can discriminate polymeric materials with very similar attenuation coefficients.

20. **Otmar Scherzer**, University of Innsbruck

    Title: Impedance-Acoustic Tomography

    Abstract:

    In this work we present a hybrid imaging technique that combines electrical impedance tomography with acoustic tomography. The novel

technique makes use of the fact that the absorbed electrical energy inside the body raises its temperature, thus leading to expansion effects. The expansion then induces an acoustic wave which can be recorded outside the body and consequently be used to calculate the absorbed energy inside the body from which the electrical conductivity can be reconstructed. In other words we try to combine the high contrast of EIT with the high resolution of ultrasound. **Joint with Bastian Gebauer.**

21. **John Schotland**, University of Pennsylvania

    Title: Inverse Problem of Acousto-Optic Imaging

    Abstract:

    We propose a tomographic method to reconstruct the optical properties of a highly-scattering medium from incoherent acousto-optic measurements. The method is based on the solution to an inverse problem for the diffusion equation and makes use of the principle of interior control of boundary measurements by an external wave field. This is **joint work with Guillaume Bal**.

22. **Plamen Stefanov**, Purdue University

    Title: Thermoacoustic tomography with a variable sound speed **Abstract:**

    We study the mathematical model of thermoacoustic tomography in media with a variable speed for a fixed time interval [0, T] so that all signals issued from the domain leave it after time T . In case of measurements on the whole boundary, we give an explicit solution in terms of a Neumann series expansion. We give almost necessary and sufficient conditions for uniqueness and stability when the measurements are taken on a part of the boundary. This is **joint work with Gunther Uhlmann.**

23. **Yuan Xu**, Ryerson University

    Title: Ultrasound mediated imaging methods for electrical properties of biological tissues

    Abstract:

It is desirable to image the electrical/optical properties of biological tissues non-invasively with high spatial resolution because the electrical/optical properties of biological tissues are closely related with the physiological and pathological status of the tissues. Several methods have been proposed to image the electrical and optical properties of biological tissues. For example, electrical impedance tomography (EIT) is used to image the electrical impedance at low-frequency range. Pure microwave and optical imaging modalities have been used to probe the absorption rate of biological tissues to electromagnetic waves. However, all the above imaging modalities that employ pure electromagnetic waves suffer from either low spatial resolution or poor imaging depth. On the other hand, ultrasound imaging can provide high-spatial-resolution images with good imaging depth. However, pure ultrasound can not reveal the optical/electrical properties of tissues. In this talk I will introduce the approach to combine ultrasound with electromagnetic waves for medical imaging to yield the information related with the electrical/optical properties of biological tissues at high spatial resolution. I will discuss three different methods to combine ultrasound with electromagnetic waves for imaging. The first category is to investigate the changes in the ultrasound echoes from biological tissues induced by an external electrical field. The second category is to detect the electrical potential difference in biological tissues caused by applying an ultrasound field to the tissues. The third category is to detect the ultrasound waves emitted by biological tissues caused by applying an electrical field to the tissues. I will introduce the principles, experimental setups, and some preliminary experimental results of these methods. The underlying physics and the signal strength will be emphasized in the talk.

Thursday October 29th, 11:00-11:40
Changhui Li, Washington University, St. Louis

Title: Photoacoustic tomography: Combing electromagnetic absorption contrast with ultrasonic detection

Abstract:
This talk will present an introduction to photoacoustic tomography (PAT), an emerging biomedical imaging modality. Over the past decade, PAT has become one of the fastest growing biomedical imaging modalities. It combines the nonionizing illumination source and the ultrasonic detection. It can image targets of micrometer-size cells to centimeter-size tumors, with imaging depth ranging from hundreds of micrometers to several centimeters in biological tissues. We will focus on the motivation, fundamental mechanism, various implementations, and limitations of this modality. We also discuss how mathematics plays an important role in this emerging imaging method.