PAI Workshop Program

"Innovative Techniques in Hybrid and Photoacoustic Imaging"

Date: 16-18 Oct. 2012
Location: Aula, Campus Altes AKH,
Campus of the University of Vienna
Spitalgasse 2, 1090 Vienna

Tuesday, October 16, 2012

8.45-9.00am ***Opening***

9.00-9.50am ***"On inverse problems with internal information"***
Peter Kuchment

It has been noticed that the success of several newly developing hybrid methods was based upon deriving the values inside the object of a function of the unknown parameters. We provide a sample to implement test of when and explanation why such information often stabilizes known highly unstable imaging methods.

9.50-10.40am ***"Biomechanical Imaging of Tissue: Forward Models and Inverse Problems Results"***
Joyce McLaughlin

The goal is to image biomechanical properties of tissue. The images are an explicit, visual representation of what the doctor feels in a palpation exam. We discuss: (1) mathematical viscoelastic models for the forward problem with multiple components of displacement; (2) the well-posedness of those models; (3) the assumption of incompressibility and how it changes the model; (4) data acquisition; (5) determining interior displacement data and how that might relate to photoacoustic data acquisition; (6) sensitivity of the data to changes in biomechanical parameters; (7) uniqueness and stability of the inverse problem; (8) the use of multiple data sets; and (9) algorithms for imaging the material parameters. The work of J. McLaughlin and her coauthors as well as others will be included in this review talk.

10.40-11.00am ***Coffee Break***

11.00-12.00am ***"Acousto-electromagnetic tomography"***
Habib Ammari

The aim of the talk will be to present recent results on acousto-electromagnetic tomography and introduce an efficient algorithm for solving the imaging problem. A proof of convergence of the algorithm as well as estimates of stability and resolution will be given. The presented results are from joint works with E. Bossy, J. Garnier, L. Nguyen, and L. Seppecher.

12.00-1.30pm ***Lunch Break***

1.30-2.30pm ***"The promise of deep clinical photoacoustic and ultrasound Imaging: Clutter elimination and equipment optimisation"***
Martin Frenz, Michael Jäger

The potential of photoacoustic (PA) imaging as an extension to classical ultrasound (US) in a real-time versatile multimodal diagnostic device has been realised since its invention back in the late '90. An important requirement for a clinically successful combination of PA and US is an adequate imaging depth of several centimetres. This is feasible in theory limited by optical attenuation and transducer noise. However, in clinical practice the epi-style setup, with combined optical and acoustic components in a single probe, results in severe clutter which can limit imaging depth to less than one centimetre. Optimisation of irradiation optics and methods for clutter reduction are therefore essential for clinical combined PA and US. We previously demonstrated that a dark-field type illumination leads to improved imaging depth over a direct illumination. Now we present a novel technique of combining irradiation optics and acoustic probe which allows dynamic manual adaptation of the irradiation geometry for a flexible optimisation of image contrast while scanning the body in a free-hand approach. We also previously demonstrated clutter reduction based on displacement compensated averaging (DCA) in breast phantom studies. Now we present clinical results of DCA clutter reduction, and in addition we developed a novel method which allows full clutter cancellation based on localised vibration tagging (LOVIT). We demonstrate in theory and experiment that LOVIT allows achieving full noise-limited imaging depth in phantom experiments. Our results represent the state-of-the-art of irradiation optimisation and clutter reduction, and are encouraging that epi-style PA imaging will finally achieve clinically the promised several cm imaging depth.

2.30-3.30p ***"Quantitative Photoacoustic Imaging"***
Ben Cox

Highly detailed photoacoustic images of parts of small animals can now be readily obtained. A set of photoacoustic images obtained at multiple wavelengths contains - in principle - information about the spatial distribution and concentration of individual molecular species. Such information would be highly valuable for physiological, pathological and pharmaceutical research. However, in general it is difficult to extract accurate concentration distributions from the photoacoustic image set, as a successful inversion requires corrections need to be made for the unknown, wavelength-dependent, distribution of light and for the unknown photoacoustic efficiency. Solutions based on diffusion models of light transport have been proposed, but these are inaccurate close to the surface, where typically a large part of the photoacoustic image lies. In this talk the general quantitiative photoacoustic imaging problem will be introduced, and an approach using gradient-based inversions and the radiative transfer equation will be described.

3.30-3.50pm ***Coffee Break***

3.50-4.50pm ***"Hybrid Inverse Problems and partial differential equations"***
Guillaume Bal

Several coupled-physics medical imaging modalities, such as Photo-acoustic tomography or Transient elastography, have been proposed and analyzed recently to obtain high contrast, high resolution, reconstructions of constitutive properties of tissues. These inverse problems, called hybrid, coupled-physics, or multi-wave inverse problems, typically involve two steps. The first step is an inverse boundary value problem, which provides internal information about the parameters. The second step, called the quantitative step, aims to reconstruct the parameters from knowledge of the internal information obtained during the first step. This talk will review several recent results of uniqueness, stability, explicit reconstruction procedures and numerical algorithms obtained for the second step with an emphasis on its relationship with systems of partial differential equations.

Wednesday, October 17, 2012

9.00-9.50am ***"In vivo preclinical photoacoustic imaging"***
Paul Beard

9.50-10.40am ***"Photo-acoustics and acousto-optics: mixing acoustics and optics for biomedical applications"***
Claude Boccara

Considering the main techniques that are used to image through scattering media, such as Biological tissue, their limits in term of resolution, depth and signal to noise ratio impose to use various approaches. If for shallow explorations one can rely on Optical Coherence Tomography that uses singly backscattered photons, just like in acoustic echography, for deeper exploration of biological tissues one has to rely on diffuse photons.

Diffuse Tomography is difficult, not only because it is an ill posed problem but also because the body is highly heterogeneous at various scales: resolution is thus practically limited to about one third of the depth. In this context coupling optics and acoustics using acousto-optics or photoacoustics was found useful to get *acoustic resolution* (typically < 1mm) at a few cm depths in order to *reveal an optical* contrast. We will illustrate the principles and some applications of these two techniques that are based on fairly different physical basis. We know that wavefront engineering has been very helpful to correct aberrations induced by atmosphere turbulence (in optics) or body induced aberrations in acoustics. In the same spirit we will point the progresses that have been achieved these last years in term of wavefront control in the space domain or in the time domain and the perspective that they open to image through aberrating and scattering media and we will show examples using time reversal photoacoustics.

Finally we would like discussing how these wavefront controls could help to revisit the field of optical tomography.

10.40-11.00am ***Coffee Break***

11.00-12.00am ***"Real-time Optoacoustic Imaging - Technical Challenges and Potential Applications"***
Daniel Razansky

Optoacoustic phenomenon is unique in a way it allows to generate complete volumetric Tomographic datasets from the imaged object using a single interrogating laser pulse. This possibility does not exist in most other imaging modalities as it is usually necessary to perform sequential excitation of the object from multiple source locations in order to acquire tomographic data required for efficient volumetric image reconstructions. Yet, multiple technical limitations exist for efficient implementation of real-time optoacoustic imaging, such as lack of appropriate ultrasound detection and laser technologies and limitations on the digital sampling and processing capacities. The talk provides the recent progress on this subject, including examples of in-vivo imaging studies.

12.00-1.30pm ***Lunch Break***

1.30-2.00pm ***"Photoacoustic Sectional Imaging"***
Peter Elbau

By focusing the illuminating laser beam of a photoacoustic measurement onto one section of the object under consideration, we could get, under ideal conditions, measurement data from an acoustic wave emanating from this one section only. These data would then allow us to recover the absorption density of the object in this section. In this talk, I would like to discuss some mathematical models for these sort of experiments and present respective reconstruction formulas for the absorption coefficient of the object.

2.00-2.30pm ***"Dual-modality section imaging system with optical Ultrasound detection for photoacoustic and ultrasound imaging"***
Robert Nuster

We propose the further development of the optical detection setup towards photoacoustic (PA) and ultrasound (US) dual-modality section imaging. Both imaging modalities use optical generation and detection of ultrasound waves. A one-sided chrome coated concave cylindrical optical lens is used as target to induce acoustic signals for US imaging and as acoustic mirror that forms acoustic images. By probing the temporal evolution of the acoustic images with an optical beam perpendicular to the acoustic axis and simultaneously rotating the object, data for reconstruction of PA and US slice images are acquired. All acoustic signals are excited optically via the thermoelastic effect using laser pulses coming from the same laser system.

2.30-3.00pm ***"Photoacoustic Imaging in Attenuating Acoustic Media"***
Konstantinos Kalimeris

In this talk we will consider acoustic attenuation in the analysis of the photoacoustic problem. In particular, we analyze some attenuating models, which come from some biological (or physical) models and possess a certain type of mathematical formulation. This analysis comes from the time-reversibility property of the wave equation. This provides an algorithm for the derivation of a reconstruction imaging functional, which gives the initial datum of the considered problem. In the attenuating models presented here, the application of this time-reversion procedure is not straightforward and some arguments for the asymptotic approximation of this process are made, which, furthermore, allow us to deal with a variety of different attenuating models.

Thursday, October 18, 2012

9.00-9.50am ***"Three-Dimensional Laser Optoacoustic Ultrasonic Imaging System and Applications"***

Alexander A. Oraevsky

This lecture will discuss the principles of operation, methods of signal processing and image reconstruction, advantages, limitations and biomedical applications of a new combined three-dimensional laser optoacoustic and ultrasound tomography system recently developed in our laboratory. The idea of combining the optoacoustic and ultrasonic imaging system in one modality for the purposes of coregistration of functional optoacoustic and anatomical ultrasonic images drives present developments in the field of optoacoustic imaging. Optoacoustic images can provide natural and useful enhancement of almost every application of medical ultrasound. Three dimensional tomography system provides the best spatial resolution and the most accurate quantitative information for tissue characterization. Optoacoustic system provides optical contrast in tissue while mapping tissue structures with high resolution unattainable in pure optical systems. The main advantages of the optical contrast is the applicability of spectroscopic optoacoustic imaging to map distributions of blood concentration and its oxygen saturation (functional imaging) in the given tissue, and map distribution of molecules of interest, such as cancer receptors or other biomarkers (molecular imaging) using nanoparticles as contrast agents. When coregistered with tissue morphology well depicted on ultrasound images, optoacoustic tomography can find itself among the most comprehensive visualization technologies for preclinical research in oncology, angiography and neurophysiology and for clinical diagnostic imaging of breast cancer and other malignancies.

9.50-10.15am ***"Fabry-Perot interferometer as line detector for photoacoustic tomography"***

Sibylle Gratt

Acoustic line detectors have been shown to be capable of providing accurate signals for three-dimensional photoacoustic tomography. Free and guided beam optical Mach-Zehnder interferometers (MZI) have been used as well as a waveguide Fabry-Perot interferometer (FPI). The ultimate sensitivity is expected from a FPI where the optical field in the resonator propagates in the acoustic coupling medium (water) surrounding the imaged object. Such a free-beam FPI is completely optically and acoustically transparent, while providing a higher sensitivity compared to the MZI due to the multiple beam interference. In this work the performance of a FPI for measurement of ultrasound waves is compared to a MZI. The design of the interferometer is presented and first measurements with an ultrasound transducer and a photoacoustic source are shown. It is shown that an at least 7-fold higher signal to noise ratio is achieved compared to a MZI.

10.15-10.40am ***"Simultaneous three-dimensional photoacoustic and laser-ultrasound tomography"***

Gerhild Wurzinger

Photoacoustic and ultrasound imaging use the same instrumentation for detection of acoustic waves. This has been used in the past to perform simultaneous imaging by using a conventional ultrasound device combined with a pulsed laser source. In this work it is shown that combined imaging can be achieved with an optical ultrasound detector, by using the same laser pulse for photoacoustic generation and for launching a broadband ultrasound pulse from an optically absorbing target. The laser-generated plane wave is scattered at the imaging object and measured with the same interferometric detector that also acquires the photoacoustic signals. In this way it is possible to collect at the same time data for photoacoustic and ultrasound images. After separation of the data, three-dimensional, co-registered images are reconstructed using back-projection. Images are shown of phantoms and of zebra fish, demonstrating the complementary information of the two imaging modalities.

10.40-11.00am ***Coffee Break***

11.00-12.00am ***"Speed of sound corrections in Photoacoustic Tomography and towards PAM II"***

Srirang Manohar

Some developments in the field of speed-of-sound corrections in photoacoustics in a computed tomography geometry are presented. We show in phantoms and biological specimens that the presence of acoustic heterogeneities can produce artefacts when using a single speed-of-sound in reconstructions. We address the problem, by ascertaining a distribution of acoustic velocity through the object simultaneous to the acquisition of conventional photoacoustic images. This is achieved with the help of a passive element generating ultrasound, which is a high absorber of light and thus a photoacoustic source, placed in the path of the incident light outside the object. The distribution of the acoustic velocity can be used to compensate for acoustic heterogeneities in the reconstruction procedure to obtain improved resolutions and contrast.

Further, some new developments in instrumentation towards the second generation Twente Photoacoustic Mammoscope (PAM II) are presented.

12.00-1.30pm ***Lunch Break***

1.30-2.00pm ***"The Acoustic Inverse Source Problem and Photoacoustic Imaging"***

Thomas Glatz

Generally formulated, the acoustic *inverse source problem* contains (the well-known acoustic part of) the *photoacoustic problem* as a special case. Nevertheless, in *inverse source theory* it is common to consider monochromatic (i.e., time-harmonic) sources, whereas in photoacoustics a short laser pulse induces an acoustic wave signal that ideally contains the whole temporal frequency spectrum. The relation between these two approaches is established by narrowband photoacoustics, where one takes into account limited frequency responses of the transducers. With this in mind, we investigate the use of PAI reconstruction methods for solving inverse problems for the Helmholtz equation. We reanalyze the effect of a narrowband recording detector analytically and present new insights concerning the dependence between band limitation and the resolution in the photoacoustic image. Moreover, we emphasize that this approach is a near field version of a novel approach by R. Griesmaier and M. Hanke for solving an inverse problem for the Helmholtz equation.

This is joint work with M. Hanke, R. Griesmaier and O. Scherzer.

2.00-2.30pm ***"Generation of a PAI-optimized zebrafish model for in vivo studies on pancreatic beta-cell regeneration"***

Nicole Schmitner

In all vertebrates beta-cells are the only natural sources of the blood-sugar regulating peptide hormone insulin and loss of beta-cells is the major cause for diabetes type I. While beta-cells in humans have very little capacity to regenerate, the genetic model organism zebrafish is able to recover from loss of beta-cells within two weeks. The rapid regeneration potential makes the zebrafish a promising model to study conserved signaling pathways regulating beta-cell neogenesis and proliferation.

A major limitation for studying beta-cell regeneration in the adult zebrafish is the optical inaccessibility of the pancreas in the middle of the abdomen. Currently the regeneration process is assessed at defined time points post mortem, which limits our view at the regeneration process. It would be preferable to study the regeneration process in vivo using multispectral photoacoustic tomography or microscopy in order to get a more accurate and dynamic view at the processes involved and analyze underlying mechanisms in more detail. To improve the detection of deeply located pancreatic cells by multispectral PAI we have established novel PAI-optimized fishlines carrying a transgene for conditional ablation of beta-cells and for in vivo labeling of beta-cells with fluorochrome E2crimson, which possesses optimal characteristics for multispectral PAI.

Following the ablation of beta cells in adult zebrafish, different possibilities regarding the beta cell regeneration mechanism are discussed. The currently available ablation system does not lead to total beta cell ablation. As studies in mouse revealed different modes of beta-cell regeneration in animals with a partial of a virtually complete loss of beta cells, we further started to explore two alternative genetically encoded conditional ablation systems that promise a complete removal of beta-cells. One method uses injection of diphtheria toxin (DT) in combination with transgene driven, beta-cell specific expression of a DT-receptor, rendering cells sensitive for DT. The second approach is based on the cell type specific expression of a cell-death inducing factor (human caspase8 fused to an FKBP dimerizing domain) which enables selective ablation via induction of apoptosis that occurs upon treatment with a chemical dimerizer. We expect that combining efficient ablation methods with PAI-based in vivo monitoring approaches will help to facilitate on new approaches to cell replacement therapies for treating diabetes type I.

LIST OF PARTICIPANTS

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