Tampereen teknillinen yliopisto. Matematiikan laitos. Tutkimusraportti 101
Tampere University of Technology. Department of Mathematics. Research Report 101

Markku Åkerblom (ed.)

20th Inverse Days 2014, Tampere 9th – 11th December 2014

Abstracts

Inverse Days
9th – 11th Dec 2014
Tampere, Finland

TAMPERE UNIVERSITY OF TECHNOLOGY

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Tuesday — 9 December 2014

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The registration table is outside the Sonaatti 2 room. Registration is open from 09:00 to 12:00. Breakfast is also served in the Fuuga room.

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11:00 Brander, Tommi
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Travel time inverse problems in space-time

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Utilizing Fokker-Planck-Eddington Equation in Diffuse Optical Tomography

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14:00 Lucka, Felix
Sample-based Bayesian Inversion

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A numerical solution for the inverse fixed energy scattering problem in 2D

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15:30 FIPS meeting — Sonaatti 2
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Signal sparsity in asteroid tomography

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Electromagnetic Flow Tomography

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Leakage Detection in Water Distribution Networks

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15:30 Mäkelä, Niko
RAP-MUSIC in EEG with neural background noise: challenges and upgrades

16:00 Lähivaara, Timo
Statistical full-wave inversion for estimating pipeline location using ground-penetrating radar data

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1. Zeinab Ahmadi Zeleti, *Lappeenranta University of Technology, Finland*
2. Giovanni S. Alberti, *Ecole Normale Supérieure, Paris*
3. Alexander Bibov, *Lappeenranta University of Technology, Finland*
4. Ismael Rodrigo Bleyer, *University of Helsinki, Finland*
5. Eemeli Blåsten, *University of Helsinki, Finland*
6. Roberta Bosi, *University of Helsinki, Finland*
7. Tommi Brander, *University of Jyväskylä, Finland*
8. Nick Dudley Ward, *University of Eastern Finland and University of Canterbury*
9. Josef Durech, *Charles University in Prague, Czech Republic*
10. Paola Elefante, *University of Helsinki, Finland*
11. Sebastian Ernst, *Deep Space Industries*
12. Georgios Fotopoulos, *University of Oulu, Finland*
13. Andoni Garcia, *University of the Basque Country, Spain*
14. Heikki Haario, *Lappeenranta University of Technology, Finland*
15. Markus Harju, *University of Oulu, Finland*
16. Tapio Helin, *University of Helsinki, Finland*
17. Jukka Huhtamäki, *Eigenor Corporation*
18. Janne Huttunen, *University of Eastern Finland*
19. Nuutti Hyvönen, *Aalto University, Finland*
20. Joonas Ilmavirta, *University of Jyväskylä, Finland*
21. Arto Julkunen, *Astrock Oy*
22. Marko Järvenpää, *Tampere University of Technology, Finland*
23. Vesa Kaarnioja, *Aalto University, Finland*
24. Mikko Kaasalainen, *Tampere University of Technology, Finland*
25. Manas Kar, *University of Jyväskylä, Finland*
26. Kimmo Karhunen, *University of Eastern Finland*
27. Hanne Kekkonen, *University of Helsinki, Finland*
28. Henrik Kettunen, *University of Helsinki, Finland*
29. Jussi Korpela, *University of Helsinki, Finland*
30. Marko Laine, *Finnish Meteorological Institute*

31. Sari Lasanen, *Sodankylä Geophysical Observatory, Finland*
32. Matti Lassas, *University of Helsinki, Finland*
33. Mari Lehti-Polojärvi, *Tampere University of Technology, Finland*
34. Ossi Lehtikangas, *University of Eastern Finland*
35. Jere Lehtonen, *University of Jyväskylä, Finland*
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40. Helle Majander, *Aalto University, Finland*
41. Meghdoot Mozumder, *University of Eastern Finland*
42. Lauri Mustonen, *Aalto University, Finland*
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46. Esa Niemi, *University of Helsinki, Finland*
47. Tuomas Nikkonen, *University of Helsinki, Finland*
48. Antti Nissinen, *University of Eastern Finland*
49. Hari Nortunen, *Tampere University of Technology, Finland*
50. Olli Nykänen, *University of Eastern Finland*
51. Mikko Orispää, *Sodankylä Geophysical Observatory, Finland*
52. Petteri Piiroinen, *University of Helsinki, Finland*
53. Valter Pohjola, *University of Helsinki, Finland*
54. Ilya Potapov, *Tampere University of Technology, Finland*
55. Mohammad Pour-Ghaz, *North Carolina State University*
56. Aki Pulkkinen, *University of Eastern Finland*
57. Zenith Purisha, *University of Helsinki, Finland*
58. Sampsa Pursiainen, *Aalto University / Tampere University of Technology*
59. Jesse Railo, *University of Jyväskylä, Finland*
60. Pasi Raumonen, *Tampere University of Technology, Finland*
61. Henri Riihimäki, *Tampere University of Technology, Finland*
62. Ville Rimpiläinen, *University of Auckland*

63. Lassi Roininen, *Sodankylä Geophysical Observatory, Finland*
64. Teemu Saksala, *University of Helsinki, Finland*
65. Mikko Salo, *University of Jyväskylä, Finland*
66. Matteo Santacesaria, *University of Helsinki, Finland*
67. Aku Seppänen, *University of Eastern Finland*
68. Valery Serov, *University of Oulu, Finland*
69. Anna Shcherbacheva, *Lappeenranta University of Technology, Finland*
70. Vladimir Shemyakin, *Lappeenranta University of Technology, Finland*
71. Samuli Siltanen, *University of Helsinki, Finland*
72. Arno Solin, *Aalto University, Finland*
73. Stratos Staboulis, *University of Helsinki, Finland*
74. Simo Särkkä, *Aalto University, Finland*
75. Mika Takala, *Tampere University of Technology, Finland*
76. Johanna Tamminen, *Finnish Meteorological Institute*
77. Tanja Tarvainen, *University of Eastern Finland*
78. Jenni Tick, *University of Eastern Finland*
79. Jussi Toivanen, *University of Eastern Finland*
80. Petri Varvia, *University of Eastern Finland*
81. Marko Vauhkonen, *University of Eastern Finland, Department of Applied Physics*
82. Esa V. Vesalainen, *University of Jyväskylä, Finland*
83. Matti Viikinkoski, *Tampere University of Technology, Finland*
84. Antti Voss, *University of Eastern Finland*
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86. Gerardo del Muro González, *University of Eastern Finland*
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Abstracts

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Study of the effective parameters for porous media modelling of wind flow through forest

Zeinab Ahmadi Zeleti, Jari Hämäläinen and Heikki Haario
Lappeenranta University of Technology, Finland

Many onshore wind farms are built in or close to forests and complex terrains due to availability of considerable potential on wind power and sparse populations of people in forested areas. However, these sites are recognized with complex flow conditions because of the large amount of turbulence and momentum sink induced by foliage canopy, branches, and trunks. Thus, it is essential to know the correct wind speed and turbulence information above or after forest for better optimization of wind park.

Much work is carried out to implement the effect of canopies into CFD (Computational Fluid Dynamics) from roughness and drag force approaches to explicitly modelling a pair of trees by two equation turbulence models as well as large eddy simulation. However, the concept of this study is to investigate the effective and useful parameters in modelling the forest canopy with porous medium approach and then validate the model with field measurement. For this purpose, a series of forest canopy characterized by dense and sparse foliated layers associated with rectangularly and hexagonally arranged ball or conical shaped trees are simulated. At the first stage, the effectiveness of parameters such as porosity, permeability, inertial resistance, tree diameter, and forest density were studied in 2D. Then, the accuracy of the proposed method in 2D was tested with 3D forest. Subsequently, the comparison between CFD simulation results and in situ measurements, obtained at Skinnarila forest, near the campus of Lappeenranta University of Technology, Finland, is satisfying and that justifies the use of this model concept for assessing more accurate wind speed for wind park purposes.

Using multiple frequencies to enforce non-zero constraints in PDE and applications to hybrid inverse problems

Giovanni S. Alberti
Ecole Normale Supérieure, Paris

In this talk I will describe a multiple frequency approach to the boundary control of Helmholtz and Maxwell equations. We give boundary conditions and a finite number of frequencies such that the corresponding solutions satisfy certain non-zero constraints inside the domain. The suitable boundary conditions and frequencies are explicitly constructed and do not depend on the coefficients, in contrast to the illuminations given as traces of complex geometric optics solutions. This theory finds applications in several hybrid imaging modalities: these constraints are needed to prove stability and to apply explicit reconstruction formulae. Similarly, multiple frequencies can be used to prove uniqueness and stability for the linearized inverse problem in acousto-electromagnetic tomography, thereby obtaining the convergence of a Landweber iteration scheme.

Stabilizing correction for approximate large-scale Kalman Filtering

Alexander Bibov and Heikki Haario
Lappeenranta University of Technology, Finland

Kalman filter is a known and widely used tool that solves the problem of deducing the state of a process based on observed data in a statistically optimal way. However, when either number of observations or dimension of the state space increases, the basic nonlinear extension of Kalman filter can not be any longer implemented in an efficient way due to necessity to store covariance data of the analysis and the natural memory issues that arise from it. Therefore, the filtering equations need to be approximated in a low-memory fashion. In this talk we present and justify approximation of direct extended Kalman filter (EKF) formulas based on L-BFGS optimization and a novel stabilization procedure. Our approach guarantees that under certain assumptions that are easy to satisfy, the covariance matrices generated by the filter remain ”physical”, i.e. non-negative definite. We also prove that our approximation has certain advantages in terms of convergence rate over the previously introduced approximations of the EKF based on quasi-Newton inversion. Finally, we assess performance of the proposed approaches by running artificial data assimilation experiments on top of the two-layer quasi-geostrophic model.

Digital speech: an application of the dbl-RTLS method for solving GIF problem

Ismael Rodrigo Bleyer and Samuli Siltanen
University of Helsinki

"Digital Speech Processing" refers to the study of a speech signal. Namely, these signals are processed in a digital representation, as for example, synthesis, analysis, enhancement, compression and recognition may refer to this process.

In this talk we are interested on solving the core problem known as "Glottal Inverse Filtering" (GIF). Commonly this problem can be modelled by convolving a pressure function (input signal) with an impulse response function (filter).

Our approach is done in a deterministic setup based on the dbl-RTLS (double regularised total least squares). Therefore our second goal is to give an overview on this novel method, algorithm and its numerical implementation - based on an alternating minimisation procedure.

Enclosure method for p-Laplace equation

Tommi Brander, Manas Kar and Mikko Salo
University of Jyväskylä, Finland

We consider a body Ω with potential u satisfying the non-linear conductivity equation

$$\nabla \cdot (\sigma |\nabla u|^{p-2} \nabla u) = 0$$

with a Lipschitz obstacle $D \subset \Omega$ and a jump in conductivity σ at the boundary ∂D: $\sigma = 1$ in $\Omega \setminus D$ and $C > \sigma > c > 1$ or $1 - c > \sigma > c > 0$ in D. We recover the convex hull of the obstacle D from the Dirichlet to Neumann map by using explicit sequences of p-harmonic functions as boundary voltages.

Commercial Exploration of Asteroids and Comets - from Synthetic Reference Models to Swarm-Based Missions

Sebastian Ernst
Deep Space Industries

Any entity undertaking mineral exploration of small bodies – asteroids and comets – for financial gain will find itself closely engaged with the scientific community in order to arrive at better models of the target mineralization. In this context, 3D data of small body interiors is highly interesting and relevant for any envisioned mining operation in space. There have been instruments on space missions and studies based on astronomical data for shedding more light on such questions. However, very little is definitely known about small body interiors and there is a still ongoing fundamental discussion about whether monolithic bodies or rubble piles are the predominant species. Without further, innovative exploration missions, those questions can not be sufficiently answered. Advanced instrument and spacecraft designs must be developed, which allow detailed gravity surveys as well as radio and possibly even seismic tomographies. For enabling comparative case studies and benchmarks of algorithms, instruments and entire mission designs prior to any launch into space, it is proposed to gradually create and establish detailed synthetic reference model datasets for a range of conceivable small bodies. Those made-up models shall cover a number of different physical properties based on plausible geological features. As an example for innovative mission concepts, it is proposed to investigate the scientific potential of a swarm of about ten nano-satellite-like spacecraft against synthetic reference models.

A numerical solution for the inverse fixed energy scattering problem in 2D

Georgios Fotopoulos
University of Oulu, Finland

We consider the direct and inverse scattering problem with fixed energy for the two-dimensional Schroedinger equation with a rather general nonlinearity. In particular, using the Born approximation we prove that all singularities of the unknown compactly supported potential from L^2-space can be obtained uniquely by the scattering data with fixed positive energy. The computation of the Born approximation is carried out using the total variation (TV) regularization method. Numerical examples with noisy data are given to illustrate the effectiveness of the method.

This is a joint work with Markus Harju and Valery Serov (University of Oulu).

Radon transforms on Lie groups

Joonas Ilmavirta
University of Jyväskylä, Finland

Can one recover a function on a closed manifold from its integrals over all periodic geodesics? This problem is easier to study when the manifold has special structure. We focus on the case when the manifold is a Lie group. A common choice is to study manifolds of negative curvature, but compact Lie groups are never negatively curved, and our methods are very different. We present applications, theorems and ideas behind the proofs. Our main result gives a simple characterization of the compact Lie groups on which the Radon transform is injective.

On the inverse elastic scattering by interfaces using one type of scattered waves

Manas Kar
University of Jyväskylä, Finland

Mourad Sini
Johann Radon Institute for Computational and Applied Mathematics (RICAM)

In this talk, we deal with the problem of the linearized and isotropic elastic inverse scattering by interfaces. We prove that the scattered P-parts or S-parts of the far field pattern, corresponding to all the incident plane waves of pressure or shear types, uniquely determine the obstacle geometry for both the penetrable and impenetrable obstacles. In the analysis, we assume only the Lipschitz regularity of the interfaces and, for the penetrable case, the Lamé coefficients to be measurable and bounded, inside the obstacles, with the usual jumps across these interfaces. This is a joint work with Mourad Sini.

A Bayesian approach to a convergence problem in continuous Tikhonov regularisation

Hanne Kekkonen, Matti Lassas and Samuli Siltanen
University of Helsinki, Finland

Let us consider an indirect noisy measurement m of a physical quantity $u \in H^r$

$$m(x) = Au(x) + \delta\varepsilon(x), \qquad x \in \mathbb{T}^d. \tag{3.1}$$

Above $\delta > 0$ is the noise magnitude and ε is white noise. Since ε is not an L^2 function we have to use modified Tikhonov regularisation to get a regularised solution $u_\delta \in H^r$. Now the real solution u_0 and the approximation u_δ are both in H^r but we can prove that

$$\|u_0 - u_\delta\|_{H^{s_1}} \to 0, \quad \delta \to 0$$

only when $s_1 \leq r + s < r - d/2$. If we study the problem only from the regularisation point of view it is hard to see why we get this upper limit for the convergence.

Next we assume that m, u and ε are random variables and use the Bayesian approach to reach the estimator u_δ. Solving the maximal a posteriori (and conditional mean) estimate is linked to solving the Tikhonov regularisation if the prior has the formal distribution

$$\pi_{pr}(u) \underset{formally}{=} c \exp\left(-\frac{1}{2}\|u\|^2_{H^r}\right).$$

In this case we can prove that the prior has to take values in some Sobolev space $H^{-\tau}$, where $-\tau < r - d/2$. Hence it is easy to see that u_δ can not converge to u_0 in H^r since the prior takes values in that space only with probability zero.

Approximation Errors in EEG Source Imaging

Alexandra Koulouri and Mike Brookes
Imperial College London

Ville Rimpiläinen and Jari P. Kaipio
University of Auckland

In electroencephalography (EEG) source imaging, the objective is to reconstruct focal sources inside the brain with the help of mathematical algorithms and electric potential measurements along the scalp. Precise head models, i.e. accurate geometry and tissue conductivities, are usually required to get a reliable result. Due to individual variations, these features would need to be determined for each patient separately. The extraction of these features, however, is a multidisciplinary, time consuming and expensive task. In this study, we show that the accurate knowledge of these features is not always necessary, because the errors related to the head geometry and conductivities can be compensated with the help of the so-called approximation error approach (AEA). Simulated test cases show that similar reconstruction accuracy could be achieved with AEA as when the accurate features are known.

Time series analysis of atmosphere and climate by state space methods

Marko Laine
Finnish Meteorological Institute

Time series analysis in atmospheric sciences and climate studies are complicated by the facts that the processes are not stationary but exhibit both slowly varying and abrupt changes in their distributional properties. These are caused irregular natural variability and by external forcing such as changes in the solar activity or volcanic eruptions. Further, the data sampling is often non-uniform, there are gaps in observations, and the uncertainty of the observations varies. When the observations are combined from various sources there will be instrument and retrieval method related biases. Thus, the study of climate related time series provides important and challenging statistical inverse problems.

Dynamic regression with state space representation of the underlying processes provides flexible tools for these challenges. By explicitly allowing for variability in the regression coefficients we let the system properties change in time and this change can be modelled and estimated, also. Furthermore, the use of unobservable state variables allows modelling of the processes driving the observed variability, such as seasonality or external forcing, and we can explicitly allow for modelling error.

The state space approach provides a well-defined hierarchical statistical model for assessing trends defined as long term background changes in the time series. The modelling assumptions can be evaluated and the method provides realistic uncertainty estimates for the model based statements on the quantities of interest. We show that a linear dynamic model (DLM) provides very flexible tool for trend and change point analysis. Given the structural parameters of the model, the Kalman filter and Kalman smoother formulas can be used to estimate the model states. Further, we provide an efficient way to account for the structural parameter uncertainty by using adaptive Markov chain Monte Carlo (MCMC) algorithm. This allows a full Bayesian estimation of trend related statistics by simulating realizations of the estimated processes.

This presentation will provide a practical solution to the methodological challenges. It is illustrated by two case studies in trend and change point analyses. First, analysis of the recovery of stratospheric ozone using time series constructed from different satellite instruments spanning the years 1984-2012. Second, a study of global warming trends in monthly mean temperature records in Finland using homogenized station values from the years 1847-2013.

Travel time inverse problems in space-time

Matti Lassas
University of Helsinki, Finland

Lauri Oksanen
University College London, United Kingdom

Yang Yang
Purdue University, USA

We consider an inverse problem for a Lorentzian spacetime (M,g). We show that the time measurements, that is, the knowledge of the Lorentzian time separation function on a submanifold Σ determine the derivatives of the metric tensor. We use this result to study the global determination of the spacetime M and a Lorentzian metric g on it when the spacetime (M,g) either has a real-analytic structure or is stationary and satisfies the Einstein-scalar field equations. The presented results are Lorentzian counterparts of the extensively studied inverse problems in Riemannian geometry - the determination of the jet of the metric and the boundary rigidity problem.

Utilizing Fokker-Planck-Eddington Equation in Diffuse Optical Tomography

Ossi Lehtikangas and Tanja Tarvainen
Department of Applied Physics, University of Eastern Finland, Kuopio, Finland

Tanja Tarvainen
Department of Computer Science, University College London, London, UK

Diffuse optical tomography (DOT) is a non-invasive imaging modality in which images of the optical properties of tissues are reconstructed based on boundary measurements of transmitted near-infrared light. Reconstruction of the tomographic images requires an accurate and computationally feasible mathematical model for light propagation inside tissues. Light propagation in tissues can be modeled using the radiative transport equation (RTE). However, solving the RTE is computationally expensive. The Fokker-Planck-Eddington equation (FPE) can be used to approximate the RTE when scattering is forward-peaked which is the typical case in biological tissues. Since the equation takes into account forward-peaked scattering analytically, coarser angular discretization can be used compared to the RTE.

In this work, an image reconstruction method for DOT based on using the FPE is developed. In the approach, absorption and scattering distributions are estimated using the Bayesian framework for inverse problems. The proposed approach is tested using simulations. Reconstructions from different cases including low-scattering domains are shown. The results show the FPE produces as good quality reconstructions as the RTE with reduced computational load.

Sample-based Bayesian Inversion

Felix Lucka
Department of Computer Science, University College London, UK

Solving ill-posed inverse problems by Bayesian inference has recently attracted considerable attention. Compared to deterministic approaches, the probabilistic representation of the solution by the posterior distribution can be exploited to explore and quantify its uncertainties. In applications where the inverse solution is subject to further analysis procedures, this can be a significant advantage. Alongside theoretical progress, various new computational techniques allow to sample very high dimensional posterior distributions. In first part of this talk, we present a recent extension of the MCMC sampler developed for ℓ_1-type priors to a wide range of priors used in Bayesian inversion, including general ℓ_p^q priors and student's t-priors with additional hard constraints. We demonstrate the abilities of the new samplers by various computed examples including total variation (TV) based inversion of experimental, fan-beam computed tomography (CT) data. In the second half of the talk, we show that the samplers can not only be used to integrate, but also to optimize the posterior distribution: Their use in simulated annealing schemes leads to algorithms for MAP estimation that are surprisingly competitive to deterministic optimization approaches. Based on all the results presented, we close by some general comments on Bayesian inversion.

Statistical full-wave inversion for estimating pipeline location using ground-penetrating radar data

Timo Lähivaara
University of Eastern Finland, Finland

Nicholas F. Dudley Ward
University of Canterbury, New Zealand

Tomi Huttunen
Kuava Ltd., Finland

Jari P. Kaipio
University of Auckland, New Zealand

Kati Niinimäki
Aix-Marseille University, France

In this work, an inverse problem of estimating the pipeline location from ground-penetrating radar data in the presence of model uncertainties is studied in the context of Bayesian inversion. Maxwell's equations are used to model the electromagnetic wave propagation in the ground. To approximate the spatial derivatives of the first order hyperbolic system, we use a high-order discontinuous Galerkin method, while the time derivatives are approximated using the explicit low-storage Runge-Kutta method. The uncertainties related to the inverse problem are taken into account by Bayesian approximation error (BAE) method. Results suggest that by using the BAE method the model uncertainties can be taken satisfactorily into account, while at the same time making a significant reduction in the computational burden. Furthermore, the location of the pipeline can be accurately estimated from noisy data.

RAP-MUSIC in EEG with neural background noise: challenges and upgrades

Niko Mäkelä and Jukka Sarvas
Aalto University, Finland

Multiple signal classification (MUSIC) and its recursively-applied version (RAP-MUSIC) can be used for locating cortical sources in magneto- and electroencephalography (MEG/EEG). These algorithms assume white noise, and their performance has been validated in simulations using only white noise. However, neural background activity that often plays the role of noise is not white but correlated, since it arises from the same source space as the signals of interest.

We evaluated the performance of (RAP-)MUSIC in the case of correlated neural noise in EEG by Matlab simulations. RAP-MUSIC performed significantly better than MUSIC for larger number of sources, but was occasionally unable to find all sources due to ripple in its scanning function. We improved the conventional RAP-MUSIC to follow and update the number of the true signal sources (FUN-MUSIC) according to the evolution of the eigenvaluespectrum of the data covariance matrix. This can increase the localizing power of multiple sources by decreasing the cumulating errors of the iterative algorithm.

In bioelectromagnetic forward and inverse computations, the orientations of the candidate dipoles in the modeled source space are often fixed perpendicularly to the cortical surface. This makes the leadfield-matrix and inverse computations simpler, compared to the case of freely oriented dipoles. However, errors in the modeled dipole orientations may lead to significant errors in the inverse solution. Based on our studies with MUSIC-family methods, we propose new techniques to circumvent the problem of choosing a forward model with completely fixed or freely oriented source candidates. The introduced methods make the MUSIC scanning algorithm simpler and more tolerant of dipole-orientation errors (loose orthoprojection of subspace topographies; LOST-MUSIC), and offer a means for setting a relaxed estimate for leadfield-array's candidate-source directions (RELACSD-MUSIC).

Leakage Detection in Water Distribution Networks

Markus Neumayer, David Steffelbauer, Markus Günther and Daniela Fuchs-Hanusch
Graz University of Technology

Water distribution networks are among the most important components of our infrastructure. Leakages in water distribution systems (WDS) can lead to supply interruptions, contaminations and economic losses. The classical leak detection approach is based on night time measurements in district meter areas. The system is structured in hydraulic districts. In this presentation we will access the detection and estimation of leakage by means of an inverse problem approach. We will present the formulation of the estimation problem within the Bayesian Framework, discuss the specifics about water distribution networks and present a stochastic model of the water distribution network, where we show the efficient incorporation of uncertain demands. Finally we will present first results for leak detection and localization.

Probabilistic methods and EIT

Petteri Piiroinen
University of Helsinki, Finland

In this presentation, we consider the probabilistic approach to the electrical impedance tomography (EIT). We will interpret the EIT forward problems via Feynman-Kac formulae for related diffusion processes. Moreover, we will give probabilistic interpretations of Calderón inverse conductivity problems in terms of boundary trace processes of reflecting diffusion processes. We will also discuss an application of these methods to stochastic homogenization.

Previously, the probabilistic techniques for EIT have required some extra regularity from the conductivity. Moreover, with the exception of non-constant conductivities, the boundary of the domain has been required to have some differentiability. The results we present relax these regularity assumptions to cover possibly anisotropic, merely measurable bounded conductivities on bounded Lipschitz domains.

The presentation is based on the joint work with Martin Simon from Johannes Gutenberg-Universität Mainz, Germany.

Morphogenetic diversity of plants: From single tree to forest

Ilya Potapov, Marko Järvenpää, Pasi Raumonen and Mikko Kaasalainen
Tampere University of Technology, Finland.

Trees play an important role in organizing ecological communities such as forests, small ecological niches, and even urban environments. This ranges from forming landscapes and habitats for other species to determining eco-physiological characteristics of the biosphere. Trees, varying in physiology and branch morphology, contribute differently to these characteristics. Thus, models accounting for the structural and physiological diversity of trees are important for identifying and analyzing major impacts that such trees exert on the environment. Usually, the functional-structural plant models (FSPM) are tuned to have certain deterministic parameters corresponding to fixed conditions. We use Lignum, FSPM for Scots pine, and modify it to account for the morphological and physiological diversity of the pine trees in a stand. Moreover, we introduce stochastic disturbances to the main parameter values resulting in distributions of the main morphological characteristics of the Lignum trees. Finally, we optimize the model by fitting the distributions to the corresponding experimental data, obtained with the latest in situ laser scanning measurements.

Electrical Impedance Tomography for Nondestructive Evaluation of Concrete

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In civil engineering, there is a considerable interest in the use of electrically-based methods for nondestructive evaluation of concrete and reinforced concrete structures. The majority of the currently used methods are empirically developed or are based on simplistic measurement strategies. Consequently, these methods are usually highly approximative and/or are limited only to certain geometries and measurement setups. Electrical Impedance Tomography (EIT) might provide a versatile tool for nondestructive evaluation of concrete, and overcome many limitations of the previous methods. In this presentation, we discuss the development of EIT for two different applications: damage detection in reinforced concrete structures using EIT-based sensing skin [1, 2], and monitoring unsaturated moisture flow in concrete [3]. We show experimental results from both applications and discuss the associated reconstruction methods.

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Signal sparsity in asteroid tomography

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Subsurface imaging of small planetary objects is a future technology to be used for research and exploitation purposes, e.g., in detection and classification of mineral resources contained by an asteroid. Recovery of massive ground structures in terrestrial land surveys involves expensive techniques such as seismic explosions, deep boreholes and high energy radars or radar arrays. From a planetary perspective, a central objective is to find a robust imaging approach that can be implemented within a restricted in situ energy supply and tight mission payload limits. If a planetary body is penetrable by electromagnetic waves, radio technology provides an accessible sounding approach compared to other potential alternatives, such as seismic blasts. Namely, target's internal relative permittivity distribution can then be recovered based on radio frequency data likewise to the ground penetrating radar (GPR/georadar) applications of today.

The general goal in our recent research has been to approximate the minimal number of source positions needed for robust localization of anomalies caused, for example, by an internal void. Characteristic to the localization problem are the large relative changes in signal speed caused by the high refractive index of typical asteroid minerals (e.g. basalt), meaning that a signal path can include strong refractions and reflections. The inversion strategy applied combines a hierarchical Bayesian inverse model and the iterative alternating sequential (IAS) posterior exploration algorithm. Methods relying on ray tracing and finite-difference time-domain (FDTD) forward simulation have been utilized in forward (data) simulation. Both simulated and real experimental data have been utilized. Special interest has been paid to robustness of the inverse results regarding changes of the prior model and source positioning. The results have been encouraging: strongly refractive anomalies can be detected already with two sources independently of their positioning, and the robustness has been observed to increase rapidly along with the number of sources.

Modeling host-seeking behavior of mosquitoes in presence of ITN intervention

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A discrete agent-based model of mosquito host-seeking behavior in presence of the ITNs (insecticide-treated nets) is based on Metropolis sampling algorithm in combination with the concept borrowed from Simulated Annealing optimization method. The model allows to assess the efficiency of the ITNs for personal protection of the human, depending on the hunting baits of a particular mosquito specie and the properties of the chemical treatment. Parameter identification was done to to fit the real data from experimental hut trials conducted to compare the efficiency of the ITNs against two malaria mosquitoes: An. Gambiae (or similar specie, An. funestus) and An. Arabiensis. Two former malaria vectors exhibit stronger persistence in blood-feeding attempts in comparison to An. Arabiensis, which additionally features avoidance of the ITNs. Model simulations display close correspondence with experimental hut trials.

The model can be applied in domains lager in space and time, and with larger host populations, providing tools for time and space dependent vectorial capacity modeling as needed in epidemiological models for mosquito-human contact based diseases, such as malaria.

EPS based parameter identification of chaotic systems

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Ensemble Prediction System (EPS) is the approach used in present day weather predictions to estimate the uncertainty of forecasts. Along with the main prediction an ensemble of simulations is launched with perturbed initial values. Recently, the EPS with simultaneous parameter estimation approach (EPPES) has been proposed to tune model parameters on-line by perturbing the parameter values in addition to initial values and monitoring the respective performance. The key point of EPPES is the estimation of parameter covariance by sequentially updating the covariance as hyperparameters by aid of importance weights. A problem, however, is the choice and weighting of cost functions, as several criteria should be simultaneously satisfied.

Here, we study the Differential Evolution (DE) optimization approach to solve the problem as a stochastic optimization task. Moreover, we present an approach to automatically scale several criteria together by a method of separate importance weights both for EPPES and DE approaches. We show that the convergence is improved using DE, in case the initial values of model parameters are far enough from the true ones.

Gaussian process priors for catching quasi-periodic noise confounds in fMRI

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Structured noise confounds are a major concern in increasing the signal-to-noise ratio in functional magnetic resonance imaging (fMRI) of the brain. Heartbeat and respiration induced periodic noises can be modeled as additive components in the data. Their time-varying (but known) frequencies and the slow sampling ratio make this an interesting inverse problem. We work under a Bayesian framework, where we encode our prior assumptions about the quasi-periodicity into our model. The method implementing these ideas is known as DRIFTER. The inference problem can be constructed equivalently as a batch inverse problem on a temporal Gaussian process or as a Kalman filtering and smoothing problem on a state-space model. We discuss this connection and demonstrate some experimental results.

Evolution equation representation of regularization in dynamic inverse problems

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This work is considered with the use of stochastic evolution equations as causal representations of spatio-temporal priors in statistical inverse problems. Example applications are in magneto- and electroencephalography (MEG and EEG), diffuse optical tomography (DOT), and electrical impedance and capacitance tomography (EIT and ECT), where accounting for the dynamics in the inverse solution is beneficial. We start by discussing the relationship of Tikhonov regularization and Gaussian random field priors, and then show how spatio-temporal random fields (and hence Tikhonov-regularizers) can be converted into weakly equivalent stochastic evolution equations. Because the corresponding spatio-temporal stochastic process is Markovian in temporal direction, the corresponding inverse problem can be efficiently solved using Hilbert-space-valued Bayesian (Kalman) filtering and smoothing. In particular, the resulting number of computations is linear in the number of time steps as opposed to typical cubic and the inference procedure easily adapts to real-time systems.

Electromagnetic Flow Tomography

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Electromagnetic flow meters (EMFMs) are a gold standard in measuring flow velocity in process industry. With this technique it is possible to measure the mean flow velocity of conductive liquids However, a drawback of this approach is that the velocity field in tomographic manner cannot be determined. An electromagnetic flow tomography (EMFT) has been recently introduced which can be used to measure the velocity fields in conductive pipe flows The EMFT contains coils that are used to produce a magnetic B-field and the plane of an electrode array, mounted on the internal surface of a non-conducting pipe wall. The resulting voltages caused by the moving fluid are measured using the electrodes. Based on the measured data the velocity field of the moving fluid (the tomographic image of the fluid flow) can be estimated. This is a classical inverse problem that can be approached with the well known inverse problem solution techniques. In this paper, the mathematical model for the EMFT is derived and the effects of the fluid flow and the applied B-field on the measured voltages are studied through computer simulations. Results for different velocity profiles with uniform and non-uniform B-fields are given. In addition, results of solving the inverse problem, i.e., estimating the velocity field based on the measured boundary voltages are given.

Experimental verification of Total Variation in 3D Electrical Impedance Tomography

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The image reconstruction problem in EIT is an ill-posed inverse problem and therefore prior information on the conductivity is needed to obtain feasible estimates. Previous studies have shown that for conductivities with sharp spatial variations, regularization schemes based on the Total Variation (TV) functional help to preserve these features.

In this study, an experimental verification of TV prior model in a three-dimensional geometry is considered. In addition, we introduce a systematical selection of the prior parameter in the TV prior. The feasibility of the proposed approach is tested with both simulations and laboratory experiments.

3D forest information: models and error

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Terrestrial laser scanning data can be used to produce quantitative structure models (QSM) of trees. Furthermore, the process can be automated to detect and reconstruct all the trees in a forest plot. The structure models we use consist of a collection of elementary blocks, e.g., circular cylinders, but other shapes are also possible.

We study models based on circular, elliptic and polygonal cylinders as well as cones and polyhedron surfaces with cylindrical support. The applicability and stability of each shape was studied using both real and simulated laser scanning data.

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