”Living the DREAM” Seminar (Aalto University)

28th of May, 2026, at 09:00 – 16:00

Lecture room 1, F175a, Health Techology House, Otakaari 3

https://aalto.zoom.us/j/68367970854?pwd=SGLuPx7jbaudKZXzsTfycj7U6yGzuC.1

Passcode: 482530

Session 1

09:00 Welcome

09:05 Vigdis Toresen: Total variation regularization with reduced basis in electrical impedance tomography

09:20 Jaakko Olkkonen: Computing measurement sensitivities in time- and frequency-domain optical tomography

09:35 Aada Hakula: A bilinear inverse problem with forward operator inaccuracy applied to diffuse optical tomography

09:50 Santeri Simanainen: Source localization of somatosensory evoked potentials recorded using stereotactic electroencephalography

Coffee break

Session 2

10:30 Jonne Annevirta: Advancing neuroscience for clinical need and impact: Physiological markers and neuroimaging for translational applications

10:45 Jesper Edström: Non-invasive functional brain network characterization in ANT DBS for epilepsy

11:00 Jussi Kiviluoto: Sensing and imaging of ultrasonically actuated surgical devices

11:15 Cain Santhan: Computation of cardiac timing intervals using continuous-wave resonant ultrasound sensing

Lunch

Session 3

13:00	Mahshid Pashootan: Data requirements for stable and reproducible EEG features in mild cognitive impairment
13:15	Emma Kamutta: Origami modeling and folding simulation via energy minimization
13:30	Kourosh Mobredi: Accelerating bio-based foam development via Bayesian optimization
13:45	Xuliang Luo: Data-driven prediction of thin-film metallic glass forming ability via Bayesian classification and experimental verificaion in the Cu-Zr-Al system
14:00	Closing words

Coffee & informal discussion

Total variation regularization with reduced basis in electrical impedance tomography

Vigdis Toresen[1]

[1]Department of Mathematics and Systems Analysis, Aalto University, Espoo, Finland

Abstract

Electrical impedance tomography (EIT) is a noninvasive imaging technique in which information about the internal conductivity of a body is reconstructed based on voltage measurements on electrodes placed on its surface. Due to the ill-posedness of the problem, dense meshes are typically needed to obtain a sufficiently accurate finite element approximation of the forward model. This can lead to impractically long computation times, which motivates the consideration of model-reduction techniques.

In this talk, we consider using reduced basis methods combined with total variation regularization in EIT. We explain how a reduced basis can be built and applied to the forward model. We then present the Bayesian framework used to derive the reconstruction algorithm. Finally, we show results of numerical experiments demonstrating that using a reduced basis can speed up the algorithm without significantly compromising the reconstruction quality or ability of the algorithm to reconstruct jumps in the conductivity.

Computing Measurement Sensitivities in Time- and Frequency-Domain Optical Tomography

Pauliina Hirvi[1], Jaakko Olkkonen[1,2], Qianqian Fang[3], Ilkka Nissilä[4]

[1] Department of Mathematics and Systems Analysis, Aalto University School of Science, Espoo, Finland
[2] Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute FGI, National Land Survey of Finland, Helsinki, Finland
[3] Department of Bioengineering, Northeastern University, Boston, MA, USA
[4] Department of Neuroscience and Biomedical Engineering, Aalto University School of Science, Espoo, Finland

Abstract

Optical tomography (OT) comprises non-invasive imaging techniques that use visible or near-infrared light to recover three-dimensional maps of absorption and scattering coefficients, or their changes relative to a baseline, inside highly scattering media such as biological tissue. Applications include, for example, functional brain imaging and early diagnosis of breast cancer.

In OT, the forward problem of light transport is commonly modelled using the radiative transfer equation (RTE), for which the Monte Carlo (MC) method is widely regarded as the gold-standard numerical solver due to its flexibility in handling complex optical systems. The associated inverse problem of recovering optical parameters from boundary measurements is non-linear and severely ill-posed. Reconstruction techniques typically rely on linearising the relationship between the measurements and changes in the optical parameters. The linearisation is obtained via the Fréchet derivative of the forward model, also referred to as the sensitivity profile, and its finite-dimensional representation as the Jacobian matrix.

In this talk, I present recent work on computing absorption and scattering sensitivities for time- and frequency-domain measurements using the MC method. I compare the resulting sensitivity profiles with those obtained from the diffusion approximation of the RTE using the finite element method.

A bilinear inverse problem with forward operator inaccuracy applied to diffuse optical tomography

Aada Hakula[1], Pauliina Hirvi[1], Nuutti Hyvönen[1]

[1] Department of Mathematics and Systems Analysis, Aalto University, Espoo, Finland

Abstract

Linear inverse problems are common in real-world applications from industry to medical imaging, but handling inaccuracies in the associated forward operators is a relatively unstudied problem. In this work, we assume that we have a set of candidate forward operator matrices and suggest principal component analysis for modeling their variation from the mean. We combine the original linear problem with the included forward operator inaccuracy into a bilinear tensor inverse problem and present two optimization algorithms and Gibbs sampling for approximately solving the problem. As a real-world test case, we apply the algorithms to account for the inaccuracy that is present in the sensitivity profiles or Jacobian matrices in diffuse optical tomography when an atlas-based model of the head anatomy is used instead of the subject's own anatomical model. We report visual and numerical improvements in the spatial localization and contrast-to-noise-ratio in reconstructions of simulated brain activity.

Source localization of somatosensory evoked potentials recorded using stereotactic electroencephalography

Santeri Simanainen[1], Lauri Parkkonen[2], Leena Lauronen[3], Matti Stenroos[4], Eero Salli[5]

[1,2,4] Department of Neuroscience and Biomedical Engineering, Aalto University, Espoo, Finland [3,5] Faculty of Medicine, University of Helsinki, Helsinki, Finland

Abstract

Stereotactic electroencephalography (SEEG) is a modality where brain activity is measured with surgically implanted depth electrodes. In addition to being a valuable clinical tool for the presurgical evaluation of focal refractory epilepsy, SEEG provides neuroscientists with a unique opportunity to study neural electrophysiology at a much finer spatial resolution than is possible with conventional noninvasive methods. However, SEEG is limited by its sparse cortical coverage and the sampling bias associated with conventional interpretation based on bipolar derivations. Furthermore, heterogeneous implantation schemes and the lack of robust methods for integrating data between patients restrict its broader application in neuroscience research. Biophysically informed source estimation could address these challenges by enabling localization of neuronal activity beyond the implanted sites and providing a direct anatomical representation of SEEG data.

As an initial step in evaluating SEEG source estimation techniques, we analyzed median-nerve somatosensory evoked potentials (SEPs) recorded from 15 epilepsy patients at Helsinki University Hospital (HUS). Using structural imaging data, we constructed individualized volume-conduction models with realistic geometry and assessed dipole-source-localization performance using both numerical simulations and the recorded SEPs. Our results indicate that source estimation, even when using relatively simple forward models, can localize focal neuronal sources with sub-centimeter accuracy. This holds even in cases where conventional interpretation is uninformative, such as when the signal originates further from the recording electrodes.

Advancing Neuroscience for Clinical Need and Impact

Physiological Markers and Neuroimaging for Translational Applications

Jonne Annevirta[1]

[1] Department of Neuroscience and Biomedical Engineering, Aalto University, Espoo, Finland

Abstract

This doctoral thesis focuses on improving the clinical usability of neuroscience methods by (i) advancing objective, feasible, and reproducible approaches for measuring human participants' cognitive and affective state via pupillometry, and (ii) for improving neuroimaging accuracy in functional near-infrared spectroscopy/diffuse optical tomography (fNIRS/DOT). The common aim is to develop methods that are both scientifically robust and practical for translational use.

A central theme in the first part of the thesis is the identification of pupillometry-based markers that can support clinical assessment and intervention development. Our preliminary results show that pupillometry can be used as a sensitive and accessible measure of task-related cognitive effort during magnetoencephalography recordings, supporting its potential as an objective marker of cognitive load. In Alcohol Use Disorder (AUD), we used pupillary responses to evaluate whether C-tactile (CT)-optimal tactile stimulation can modulate alcohol cue reactivity. The findings suggest reduced cue-evoked arousal in AUD patients after CT stimulation and support further development of non-pharmacological intervention strategies for AUD.

In the second part of the thesis, we address methodological limitations in fNIRS/DOT and develop approaches to improve anatomical localization, reproducibility, and ease of use. Together, these studies aim to strengthen the methodological foundations of clinically oriented neuroscience and support the development of tools that are more accurate, practical, and impactful in real-world settings.

Non-invasive functional brain network characterization in ANT DBS for epilepsy

Jesper Edström[1,2], Soila Järvenpää[3], Kai Lehtimäki[4], Päivi Nevalainen[5], Jukka Peltola[3], Hanna Renvall[1,2], Amande Pauls[2,6]

[1] Department of Neuroscience and Biomedical Engineering, Aalto University, Espoo, Finland
[2] Biomag Laboratory, HUS Diagnostic Center, Aalto University, University of Helsinki, and Helsinki University Hospital, Helsinki, Finland
[3] Department of Neurology, Tampere University Hospital, Tampere, Finland
[4] Department of Neurosurgery, Tampere University Hospital, Tampere, Finland
[5] Department of Clinical Neurophysiology, HUS Diagnostic Center, University of Helsinki, and Helsinki University Hospital, Helsinki, Finland
[6] Department of Neurology, Helsinki University Hospital, and Department of Clinical Neurosciences (Neurology), University of Helsinki, Helsinki, Finland

Abstract

Deep brain stimulation (DBS) of the anterior nucleus of the thalamus (ANT) is a promising treatment option for drug-resistant epilepsy (DRE) patients ineligible for resective surgery. ANT DBS has been shown to reduce seizure frequency (SF) by 50-70% after five stimulation years. However, the clinical outcome of ANT DBS is highly variable between individuals and depends on DBS programming parameters such as the location of the active contact, but we continue to lack markers to guide individualized DBS programming.

The Percept™ PC (Medtronic Inc.) is the first commercially available neurostimulator able to both stimulate and record local field potentials (LFPs) from the chronically implanted DBS electrodes. LFP recordings combined with non-invasive functional brain imaging techniques such as magnetoencephalography (MEG) could provide information about the cortical brain networks modulated by ANT DBS, which could be useful for elucidating mechanisms underlying DBS effects and optimizing stimulation settings.

This study measured simultaneous resting-state MEG and thalamic LFP signals in DRE patients to characterize the spatial and spectral properties of the coherence between the ANT and various cortical regions. The thalamocortical coherence peaked in the theta (4-8 Hz) frequency band, and depended on the subjects' vigilance state. Different ANT depths connected to distinct but still highly overlapping cortical networks that mainly included ipsilateral prefrontal and temporal regions, which matches the anatomical connections of the ANT. Further research is needed to understand the relationship between thalamocortical coherence, anatomical lead location and clinical outcomes.

Sensing and imaging of ultrasonically actuated surgical devices

Jussi Kiviluoto[1], Cain Santhan[1], Yohann Le Bourlout[1], Heikki J. Nieminen[1]

[1] Department of Neuroscience and Biomedical Engineering, Aalto University, Espoo, Finland

Abstract

Ultrasonically actuated surgical devices are medical devices consisting of an invasive surgical instrument *e.g.*, a needle or a blade, connected to an ultrasonic actuator. This study is focused on flexurally oscillating medical needles. These devices employ a longitudinally oscillating Langevin transducer, which is connected to the medical needle *via* a waveguide. This translation of the oscillations also facilitates the transition of the oscillatory motion to a flexural mode. Currently, the flexurally oscillating medical needles are considered for biopsy and histotripsy treatments.

The sensing and imaging of these instruments in operation, along their effects, is crucial for efficiency and safety. The focus of the study is in the detection, quantification, and tracking of the tissue effects of the actuated needles. Exemplary targets of analysis are the accurate position of the instrument *in vivo* and the location and magnitude of a histotripsy lesion generated by the instrument. Considering this aim, novel US imaging radio frequency data analysis methods are developed and experimentally validated, supported by conventional methodologies. Experimentation in *ex vivo* tissue models allows for histological analysis of the ground truth.

Current efforts focus on temporally evolving horizontally normalized Shannon entropy imaging of radio frequency US signals for lesion quantification and US echo frequency cross correlation methods for instrument tracking.

Computation of cardiac timing intervals using continuous-wave resonant ultrasound sensing

Cain Santhan[1], Heikki Seppä[1], Heikki J. Nieminen[1]
[1]Department of Neuroscience & Biomedical Engineering, Aalto University, Espoo, Finland

Abstract

Non-invasive assessment of cardiac electromechanical timing is useful for characterizing systolic function, monitoring therapy and detecting hemodynamic decompensation. Continuous-wave resonant ultrasound sensing by driving a piezoelectric element at mechanical resonance and tracking changes in its complex electrical admittance can be used for tissue motion and loading without time-of-flight imaging. We investigated whether this architecture can be used at the chest wall to derive cardiac timing intervals from a single, low-frequency transducer.

A custom device integrating a 40 kHz piezo-MEMS resonator, a simple EKG setup and a microphone was placed over the aortic auscultation area of a healthy volunteer at rest. Simultaneous in-phase and quadrature signals from the resonator, ECG and PCG were recorded. From the complex resonant response, a propagation-velocity-like waveform at the sensor–tissue interface was computed, a high-contrast derivative signal and a displacement-like waveform were obtained by numerical differentiation and integration, respectively. Beat-by-beat fiducial points were identified on the ECG, PCG envelope and propagation-velocity derivative.

From these landmarks, standard systolic time intervals, including electromechanical activation time, pre-ejection period, isovolumetric contraction time and left-ventricular ejection time, were calculated. The propagation-velocity derivative exhibited a stable, pulsatile morphology that was tightly phase-locked to ECG and PCG, with its dominant complex consistently initiating during ventricular systole, just after the first heart sound and coincident with the putative aortic valve opening. Peak times derived from the resonant signal closely matched ECG-based timings on a beat-by-beat basis, and the relationships among the derived intervals were physiologically coherent. These findings suggest that continuous-wave resonant ultrasound can provide chest-wall propagation-velocity and displacement waveforms from which clinically relevant cardiac timing intervals can be obtained using a single, compact sensor.

Data Requirements for Stable and Reproducible EEG Features in Mild Cognitive Impairment

Mahshid Pashootan[1,2], Shrikanth Kulashekhar[1,2], Antti Kinnunen[1,2], Timo Saarinen[1,2], Ville Mäntynen[1,2], Irina Anurova[1,2], Niina Kanerva[1,2], Saara Mäkituuri[1,2], Neea Vuorenhela[1,2], Jaakko Hotta[1,2], Anne Koivisto[1,2], Mia Liljeström[1,2], Hanna Renvall[1,2]

[1] Department of Neuroscience and Biomedical Engineering, Aalto University, Finland
[2] BioMag Laboratory, HUS Diagnostic Center, Helsinki University Hospital, Finland

Abstract

Mild Cognitive Impairment (MCI) refers to a stage between normal aging and clinical dementia, of which Alzheimer Disease (AD) is the most common endpoint. Symptoms of AD appear years after the first pathological changes in the nervous system begin: early neurophysiologicalbiomarkers could enable diagnosis already at the MCI stage. With electroencephalography (EEG), the brain's electrical activity can be measured noninvasively with high temporal resolution. EEG reflects structural and functional changes in the brain and thus has considerable potential for clinical biomarkers. However, the reproducibility of EEG features suggested as AD biomarkers has not been established in MCI participants, mainly due to lack of data from large homogeneous studies with well-defined subjects. Here data from 100 participants in the recent AI-Mind study (Haraldsen et al., 2024) were analyzed. Resting-state EEG was recorded at the BioMag Laboratory in Helsinki using a 128-channel EEG system. We evaluated the within-session stability of power spectral features across varying data durations, preprocessing approaches, vigilance levels, and eyes open versus eyes closed conditions. Our preliminary results indicate minimal differences between manual and automated preprocessing, suggesting that for clinical diagnostic purposes automatized EEG preprocessing provides good data quality for biomarker identification in MCI subjects. We also propose minimum EEG data requirements and preprocessing standards to achieve stable and reproducible features in MCI populations, enhancing early-stage biomarker research for Alzheimer's disease.

References

[1] Haraldsen IH, Hatlestad-Hall C, Marra C, et al. AI-Mind clinical study protocol. Front Neurorobot. 2024;17:1289406.

Origami modeling and folding simulation via energy minimization

Emma Kamutta

Department of Mathematics and Systems Analysis,
Aalto University

Abstract

Origami modeling and simulation of expected folding behavior is a problem that has been approached in many ways ranging for example from kinematics to finite element method and multiphysics simulations in the multidisciplinary field of origami science. Inspired by the online tool Origami Simulator, we interpret the problem of solving a folded configuration of an origami piece from its crease pattern as an energy minimization problem and implement our own solver for it on MATLAB. This is a difficult optimization problem since the pattern undergoes large nonlinear deformations and has a large number of constraints. In our implementation, we model the origami as a bar and hinge model without any material parameters, leading to an ideal material mathematical abstraction of the pattern. As a test subject, we use the Miura-ori pattern which is known for its many applications and predictable single degree of freedom movement. With the pattern, we study the convergence of the simulation under different criteria.

Accelerating Bio-Based Foam Development via Bayesian Optimization

Kourosh Mobredi[1], Juha Koivisto[1], Mikko Alava[1]

[1] Department of Applied Physics, Aalto Univeristy, Espoo, Finland

Abstract

The increasing demand for sustainable materials has positioned bio-based foams as promising alternatives to petroleum-derived counterparts. However, limited functional performance and the resource-intensive nature of experimental optimization remain significant barriers to industrial adoption. Since diverse applications require specific mechanical or chemical profiles, a universal formulation is impractical. This study addresses these challenges by developing a **Bayesian multi-objective optimization framework** to identify tailored compositions for cellulosic-based foams with minimal experimental overhead.

The framework utilizes **Gaussian Process** surrogate models and an **Expected Hypervolume Improvement (EHVI)** acquisition function to guide an active learning loop. Starting with a sparse initial dataset of only 17 samples, the model evaluated three key additives—lignin, graphite, and precipitated calcium carbonate—to optimize for mechanical stability and hydrophobicity.

Key results from this study include:

- **Mechanical Reinforcement:** The optimized formulation achieved a 90–157% increase in Young's modulus, compared to the initial samples.
- **Enhanced Hydrophobicity:** The foam maintained stable hydrophobic behavior for over 20 minutes, a critical factor for functional packaging stability.
- **Efficiency:** The iterative active learning scheme significantly reduced the required number of experiments compared to traditional trial-and-error methods.

By integrating experimental data with an intelligent planning strategy, this approach demonstrates a systematic, data-efficient pathway for material R&D. The results highlight the potential for Bayesian optimization to accelerate the development of high-performance, sustainable materials in alignment with evolving global material regulations.

Data-Driven Prediction of Thin-Film Metallic Glass Forming Ability via Bayesian Classification and Experimental Verification in the Cu-Zr-Al System

Xuliang Luo[1], Tero Mäkinen[1], Wenyi Huo[2], Silvia Bonfanti[2], Zhehao Chen[3], Kenichiro Mizohata[3], Kostas Sarakinos[3], Mikko Alava[1]

[1] Department of Applied Physics, Aalto University, Espoo, Finland
[2] NOMATEN Centre of Excellence, Otwock, Poland
[3] Department of Physics, University of Helsinki, Helsinki, Finland

Abstract

Metallic glasses (MGs) are a class of non-crystalline alloys characterized by the absence of long-range order while often exhibiting pronounced short-range ordering. This atomic arrangement yields materials with unique combination of physical properties.

The formation of an amorphous structure in metal alloys is a non-equilibrium process, in which the liquid is rapidly cooled to bypass crystallization. A key metric in this context is the glass forming ability (GFA), which describes the ease with which a metallic alloy can form a glass.

At present, there is no universal rule to design MGs, and conventional experimental screening is costly. Identifying alloy compositions suitable for metallic glass formation from the vast and multi-dimensional space of elemental combinations remains a significant challenge.

In the present study, we develop - using literature data - a Bayesian machine learning model based on Gaussian processes for predicting the GFA of metal-alloy compositions, the model achieves a prediction accuracy of 87%. The prediction is experimentally verified in Cu-Zr-Al thin film alloy by magnetron sputtering, the results confirm the compositional dependence of GFA and demonstrate the effectiveness of our combined computational–experimental approach for guiding thin-film metallic glasses and amorphous alloy discovery.