# Living the DREAM Seminar series

UEF

Wednesday, May 6th, 2026, at 09:00 – 16:00

Snellmania, SN201

Zoom: `https://uef.zoom.us/j/69707049668?pwd=7b8l4JIij84T82vlJHKbu4e2dzxdka.1`
Meeting ID: 697 0704 9668
Passcode: 774588

## Session 1

09:00 Welcome
09:05 Sobuz Rana *Nocturnal Heart Rate Variability Estimation from 3D Seismocardiography Using Deep Learning*
09:20 Zewen Zhuo *Instance Segmentation of Dendrites from 3D-Electron Microscopy Images*
09:35 Markus Tolvanen *Photoacoustic contrast for virus-like nanoparticles*
09:50 Karoliina Puronhaara *Utilising a learned forward operator in the inverse problem of photoacoustic tomography*

## Coffee break

## Session 2

10:30 Niilo Saarlemo *Image reconstruction methods for single photon emission computed tomography*
10:45 Mary Joy Erojo *Simulation of SPECT Myocardial Perfusion Imaging using numerical cardiac phantoms*
11:00 Razieh Azizi *Multi-Resolution Reconstruction for Extended Field-of-View in Cone-Beam CT*
11:15 Abdulazeez Afolabi *Bayesian state estimation of dynamic greenhouse gas emissions in facility scale from multi-open-path measurements*

## Lunch (self-paid)

## Session 3

13:15 Ebawak Wodajo *Bridging Scales: Adapting RAPSODI for High-Precision Rat Brain MRI-Histology Co-Registration*
13:30 Ali Farki *Forecasting Future Anatomies: Longitudinal Brain MRI-to-MRI Prediction*
13:45 Simo Heikkinen *Simulator for low-field MRI*
14:00 Shubo Yan *Advanced Data Analysis of Non-proton Metabolic Magnetic Resonance Imaging*

## Coffee break

## Session 4

14:45 Fatemeh Maleki Almani *A Dirichlet-to-Neumann map-based model reduction framework for three-dimensional electrical impedance tomography*
15:00 Ruslan Lagashkin *End-to-end electrical impedance tomography: custom sub-second hardware and lightweight neural networks*
15:15 Fatemeh Jalali *Patient-Specific Biomechanics in Late-Stage Knee Osteoarthritis: Gait, Load Distribution, and Pain*
15:30 Alexander K. Beattie *Measurement Modalities: Towards Measuring Human Movement Outside the Laboratory*
15:45 Closing words

## 16:00–17:30 Pizza and networking

# Nocturnal Heart Rate Variability Estimation from 3D Seismocardiography Using Deep Learning

Sobuz Rana[1], Jukka A. Lipponen[1], Mika P. Tarvainen[1]

[1] Department of Technical Physics, University of Eastern Finland, Kuopio, Finland

## Abstract

Heart rate variability (HRV) is an important physiological biomarker associated with autonomic nervous system activity. Nocturnal HRV is widely used in sleep analysis, stress management, and monitoring recovery from physical training. Seismocardiography (SCG) is a noninvasive sensing modality that captures subtle chest wall vibrations produced by the mechanical activity of the heart. While SCG has shown promise for HRV estimation, existing methods largely rely on conventional signal processing, which may limit robustness in noisy, long-duration recordings. In contrast, deep learning approaches, capable of automatically handling noisy segments with high precision, remain underexplored in nocturnal HRV monitoring. This study evaluates the applicability of a previously developed deep neural network (DNN)-based method for HRV estimation from nocturnal SCG recordings.

HRV was estimated from 3D SCG signals using a U-Net-based model, trained on short resting SCG recording from 4620 subjects. The model was evaluated on the publicly available NightbeatDB dataset, which consists of 38 overnight sleep recordings collected in real-world environments, totaling approximately 290.7 hours of data. Heart rate (HR) and HRV parameters were calculated from 10-minute segments and compared against time-aligned ECG-derived reference values. For HR estimation, the model achieved a strong correlation with ECG-derived HR, with a correlation coefficient of 0.982. The mean bias was -0.3 bpm and the 95% limits of agreement (LoA; mean$\pm$ 1.96$\times$SD) ranged from -1.7 to 1.0 bpm. HRV was further assessed using the root mean square of successive differences (RMSSD), a commonly used indicator of parasympathetic activity. The estimated RMSSD showed a high correlation coefficient of 0.929, with a mean bias of 0.6 ms and LoA ranging from -10.0 to 11.1 ms.

These results demonstrate the feasibility of using nocturnal SCG signals combined with deep learning techniques for reliable HRV estimation in real-world sleep monitoring scenarios.

# Instance Segmentation of Dendrites from 3D-Electron Microscopy Images

Zewen Zhuo[1], Ilya Belevich[3], Ville Leinonen[2], Eija Jokitalo[3], Tarja Malm[1], Alejandra Sierra[1], Jussi Tohka[1]

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## Abstract

Segmenting cellular structures in electron microscopy (EM) images is essential for studying the morphology of neurons and glial cells in both healthy and diseased brain tissue, but manual annotation remains labor-intensive and time-consuming. Although convolutional neural networks have improved EM image segmentation, their reliance on local feature extraction can limit the use of broader image context. Transformer-based models offer a promising alternative, and the Segment Anything Model (SAM) has recently shown strong segmentation performance in natural images. In this study, we investigated whether SAM can be adapted to microscopy data to improve segmentation accuracy and annotation efficiency in neuroanatomical research.

We fine-tuned models from micro-SAM on in-house serial block-face scanning EM datasets with a cutting interval of 40 nm. Dataset A, obtained from the CA1 region of the hippocampus of a healthy rat, contained 1044 slices and was used for training and internal evaluation. External evaluation was performed on Dataset B, consisting of 698 slices from the same region after pilocarpine-induced status epilepticus in a rat, and Dataset C, consisting of 697 slices from a cortical layer II biopsy of a patient with idiopathic normal pressure hydrocephalus. Model performance was assessed using the object-level error metric [1].

Using prompts derived from ground-truth masks and taking the mask quality of bounding-box prompts as a benchmark, the fine-tuned ViT-B and ViT-L models improved performance by approximately 19.1% and 20.8% over the original SAM, and by 150.1% and 181.9% over micro-SAM, respectively. A user study further showed that the fine-tuned model allowed annotators to produce segmentations more consistent with ground truth while reducing annotation

time. To improve automatic inference, we also integrated YOLO to generate bounding-box prompts, addressing the limitations of grid-point-based autoprompting. This framework may also support pseudo-mask generation in future work and contribute to 3D dendrite connectome reconstruction.

# References

[1] Zhuo, Z., Belevich, I., Leinonen, V., Jokitalo, E., Malm, T., Sierra, A., and Tohka, J. *Segment anything for dendrites from electron microscopy.* In *2025 IEEE 6th International Conference on Image Processing, Applications and Systems (IPAS)*, pp. 1–6, 2025.

# Photoacoustic contrast for virus-like nanoparticles

Markus Tolvanen[1], Jarkko Leskinen[1], Jenni Poimala[1], Tanja Tarvainen[1]

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## Abstract

Photoacoustic tomography (PAT) is an imaging technique based on the photoacoustic effect [1]. In the photoacoustic effect, a short light pulse is absorbed by light-absorbing molecules (chromophores), resulting in the generation of ultrasound waves in the target being imaged. By measuring the ultrasound waves around the target using an ultrasound detector, and applying mathematical image reconstruction method, an image of the initial pressure distribution – reflecting the distribution of chromophores – can be reconstructed. Due to its high optical contrast, i.e. sensitivity to chromophores, PAT has various medical applications including vascular, skin, cancer, and small-animal imaging. In addition to endogenous tissue chromophores such as hemoglobin in blood, exogenous contrast agents that enhance image contrast and provide a platform for therapy are being developed for PAT [2].

In this thesis project, the goal is to develop new tools and applications for biomedical photoacoustic imaging. In the first part of this thesis, a new virus-like nanoparticle (VLNP) contrast agent for PAT is developed and characterized. The performance of these VLNPs is evaluated using controlled spectral photoacoustic signal measurements and photoacoustic tomography experiments in animal tissue. Tomographic images are obtained using Bayesian reconstruction methods developed in the group [3].

[1] L.V. Wang, J. Yao. "A practical guide to photoacoustic tomography in the life sciences," *Nat. Methods* (**13**), pp. 627–638, 2016.

[2] W. Xu, et al. "Assembly of fluorophore J-aggregates with nanospacer onto mesoporous nanoparticles for enhanced photoacoustic imaging," *Photoacoustics* (**33**), pp. 100552, 2023.

[3] J. Tick, et al. "Three dimensional photoacoustic tomography in Bayesian framework," *J. Acoust. Soc. Am.* 144(**4**), pp. 2061–71, 2018.

# Utilising a learned forward operator in the inverse problem of photoacoustic tomography

Karoliina Puronhaara[1], Teemu Sahlström[1], Andreas Hauptmann[2,3], and Tanja Tarvainen[1]

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## Abstract

Photoacoustic tomography (PAT) is a hybrid medical and biomedical imaging modality that combines unique optical contrast with the high resolution of ultrasound [1]. Applications of PAT include, for example, imaging of skin and breast tumours, microvasculature, and small animals. In PAT, a short nanosecond scale light pulse, is directed to the target. Absorption of this light generates increases in pressure, which relax as ultrasound waves that can be measured on the boundary of the target. In the inverse problem of PAT, the initial pressure is estimated from the measured ultrasound signals by solving an inverse problem. Numerical solving of the problem can be computationally expensive due to the need for repeated evaluations of a forward operator describing ultrasound propagation.

In this work, we study a deep learning-based method for approximating ultrasound propagation in PAT [2]. The solution of the inverse problem is estimated using a gradient-based method using a learned forward operator based on the Fourier neural operator (FNO) [3]. The approach is studied using numerical simulations in full and limited-view sensor geometries. The results are compared to a conventional method, where solution of the forward model is numerically is approximated using the pseudospectral $k$-space method. Simulations show that the FNO can be used as a computationally efficient forward operator in the inverse problem of PAT.

[1] P. Beard, Biomedical photoacoustic imaging, *Interface Focus*, 1:602–631, 2011.

[2] K. Puronhaara, T. Sahlström, A. Hauptmann and T. Tarvainen, Utilising a learned forward operator in the inverse problem of photoacoustic tomography, Manuscript in preparation, 2026.

[3] Z. Li, N. Kovachki, K. Azizzadenesheli, B. Liu, K. Bhattacharya, A. Stuart, and A. Anandkumar, Fourier neural operator for parametric partial differential equations, *International Conference on Learning Representations (ICLR)*, 2021.

# Image reconstruction methods for single photon emission computed tomography

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[1] Department of Technical Physics, University of Eastern Finland, Kuopio, Finland

## Abstract

The recent advances within solid-state radiation detection technology have the potential to enable quantitative dynamic imaging with single photon emission computed tomography (SPECT). Modern devices have transformed towards having more, but physically smaller, detector panels. This in turn allows for more spatial coverage of the field-of-view (FOV) in a unit time. Dynamic image reconstruction requires inherently different regularization and modelling strategies than conventional static image reconstruction. For example, the dimensionality of the problem grows quickly with the amount of time steps used.

For easy testing and validation of reconstruction methods, part of this work includes implementing SPECT reconstruction capabilities to OMEGA reconstruction software. This allows for implementing a grid of voxels with irregular resolution, centered around the region of interest. These multi-resolution models have previously been used in local computed tomography (CT) with promising results. Future work includes subspace projection in temporal regularization. In practice, enough time-activity curves are to be simulated to allow for projecting the image estimates during reconstruction onto this subspace.

**Simulation of SPECT Myocardial Perfusion Imaging using numerical cardiac phantoms**

Mary Joy Erojo, Matti Kortelainen, Ville-Veikko Wettenhovi, Marko Vauhkonen, Ville Kolehmainen, Mikko Hakulinen

Heart disease remains one of the leading causes of mortality worldwide. Myocardial perfusion imaging (MPI) using single photon emission computed tomography (SPECT) is widely employed to assess myocardial perfusion and cardiac function. To study image quality, accuracy, and imaging parameters, experimental phantom acquisitions are typically performed. In addition, SPECT MPI acquisitions can be simulated numerically using computational models that incorporate realistic anatomical structure, left ventricular (LV) wall motion and tissue properties. This study aims to simulate SPECT MPI acquisition using realistic cardiac phantom models and clinical imaging parameters. The cardiac phantoms are constructed from the MR-based segmentations of the myocardium wall across one cardiac cycle, combined with CT-based segmentations of the thorax and surrounding organs. Monte Carlo simulations using GATE software are performed using these phantoms in conjunction with a digital 3D Cadmium Zinc Telluride (CZT) SPECT scanner model, incorporating relevant clinical imaging parameters such as activity, number of projections, and imaging time. The projections are reconstructed using both the vendor-provided software and the inhouse OMEGA reconstruction framework. Preliminary results demonstrate the feasibility of realistic SPECT myocardial imaging simulations. This approach has potential applications in the optimization of imaging parameters, image denoising, and generation of high-quality training data for deep learning applications, among others.

**Collaboration.** This research is a collaborative effort between the Department of Technical Physics, University of Eastern Finland and Kuopio University Hospital. The research group has ongoing technical collaboration with Spectrum Dynamics Medical, which provides system-specific information about the SPECT scanner. The development of the numerical model for the digital 3D CZT SPECT system is conducted as a separate project led by A. Etxebeste and D. Sarrut from CREATIS, INSA-Lyon. The development of the OMEGA reconstruction algorithm for the digital SPECT is a separate project by N. Saarlemo et al.

# Multi-Resolution Reconstruction for Extended Field-of-View in Cone-Beam CT

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## Abstract

Cone-beam computed tomography (CBCT) is a three-dimensional medical imaging technique that uses a cone-shaped X-ray beam to acquire an image in a single rotation. CBCT often suffers from truncation artifacts, commonly referred to as out-of-FOV artifacts, when the object is larger than the field of view (FOV). These artifacts appear near the boundaries of the truncated region and occur because portions of the projection data are missing. To address this issue, we propose a separated multi-resolution extended FOV (MR-EFOV) reconstruction approach. The method extends the FOV in each direction where truncation occurs, ensuring that the entire object is sufficiently covered. To reduce computational cost, the extended regions are reconstructed using larger voxel sizes, while the main FOV is preserved at high resolution. In addition, projection extrapolation is incorporated to eliminate residual boundary artifacts. The reconstruction is performed within a least-squares optimization framework and solved using the primal–dual hybrid gradient (PDHG) algorithm. The proposed MR-EFOV method successfully removes out-of-FOV artifacts, suppresses bright boundary streaks, and accurately estimates missing information in the truncated regions, resulting in improved image quality and more reliable HU values.

# Bayesian state estimation of dynamic greenhouse gas emissions in facility scale from multi-open-path measurements

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## Abstract

Quantification of greenhouse gas (GHG) emissions at facility scale is essential for the implementation of effective transparent GHG reporting, part of emission mitigation strategies. Continuous monitoring systems based on multi-open-path laser spectroscopy enable long-term measurement of path-averaged GHG concentrations across industrial sites. However, translating these measurements into reliable source localization and emission rate estimates remains challenging, particularly under variable meteorological conditions and complex facility geometries.

This work utilizes a three-dimensional Bayesian State Estimation (BSE) framework for dynamic GHG emission reconstruction from continuous multi-open-path concentration measurements. The method combines a physics based convection-diffusion model, discretized using the finite element method, with BES, particularly fixed-lag Kalman smoothing, to estimate the evolving GHG concentration field and emission source distribution over a facility. Unlike steady-state inversion approaches, the proposed framework explicitly accounts for temporal variability, model uncertainty, and measurement noise within a probabilistic state-space formulation.

The overall aim of this PhD thesis work is to apply BSE-based GHG emission mapping experimentally in multiple test sites, such as biogas production facilities. At the first stage of this project, we study the sensitivity of the technique to various factors, such as wind variability, source dynamics and constraints applied computationally in BSE. For this purpose, the BSE is first tested with

numerical simulation studies and subsequently, with experimental data from a controlled methane release test.

# Motion Correction in k-space for ZTE fMRI

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## Abstract

Functional magnetic resonance imaging (fMRI) relies on the continuous acquisition of brain volumes to map neural activation. These measurements are highly susceptible to subject motion, such as respiratory fluctuations and muscle movements, which severely degrade data quality. Zero Echo Time (ZTE) fMRI presents an attractive, acoustically quiet, and geometrically distortion-free alternative to conventional fMRI sequences [1]. However, the inherently low tissue contrast in ZTE limits the efficacy of traditional volume-to-volume image registration. Furthermore, these conventional image-based methods inherently fail to resolve continuous intra-volume motion.

To address these limitations, we propose a novel motion correction framework applied directly in the frequency domain (k-space). Our method leverages the fundamental rotation and translation properties of the Fourier transform. For rotation correction, we use 3D cross-correlation between the moving and target k-space volume. We evaluated this method using numerical simulations, where we first artificially displaced baseline k-space volumes by known rotations. We then assessed the algorithm's accuracy by recovering these ground-truth parameters, demonstrating robust performance even when utilizing downsampled k-space data.

Because translation is a continuous process, we correct it by estimating temporally smoothed phase differences across volumes and subtracting them from original phases. We evaluate this directly on in-vivo fMRI data acquired from the brain and spinal cord of rats. To quantify the extent of motion and validate our correction, we track the shifts in the center of mass and compute volume-to-volume cross-correlation relative to the first volume. Furthermore, the overall efficacy of our framework will be benchmarked against both uncorrected data and conventional image registration, with the aim of demonstrating improvements in the resulting functional activation maps.

## References

[1] Mangia, S., Michaeli, S., and Gröhn, O. (2026). *Outlook on zero/ultrashort echo time techniques in functional MRI.* Magnetic Resonance in Medicine, 95(2):714–723.

# Bridging Scales: Adapting RAPSODI for High-Precision Rat Brain MRI-Histology Co-Registration

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## Abstract

Multimodal co-registration of magnetic resonance imaging (MRI) and histology is essential for linking macrostructural and microstructural information in brain research, but remains challenging due to large differences in image contrast, scale, and tissue deformation. In this work, we adapted the RAPSODI image registration framework [1], originally developed for prostate MRI–histopathology alignment, to the co-registration of rat brain histology and *ex vivo* MRI.

The dataset was acquired from a lateral fluid percussion traumatic brain injury model and included naïve, sham, and moderate traumatic brain injury subjects. *Ex vivo* T1-weighted MRI was acquired at 11.7 T with 100 µm isotropic resolution, and corresponding histological sections were imaged at 0.1369 µm × 0.1369 µm in-plane resolution with 30 µm section thickness.

Preprocessing included identification of missing sections, binary mask generation for both modalities, and histology downsampling to make slice-to-volume reconstruction computationally feasible. Affine registration was then performed within the RAPSODI pipeline to align reconstructed histology slices to the MRI volume. Registration accuracy was evaluated using manually selected anatomical landmark pairs distributed across multiple brain regions, including cortex, ventricles, corpus callosum, and gray–white matter boundaries.

Qualitative assessment showed good anatomical correspondence after alignment, and quantitative evaluation using Euclidean centroid distance demonstrated encouraging accuracy, with 73 % of landmark pairs falling within a sub-voxel to low multiple-voxel error range relative to MRI resolution. These findings indicate that adapting RAPSODI for rat brain MRI–histology co-registration is feasible for multimodal analysis in preclinical neuroimaging. Future work will extend the evaluation to more subjects, deformable registration methods, and additional histology stains and MRI contrasts.

## References

[1] M. Rusu, et al. *Registration of presurgical MRI and histopathology images from radical prostatectomy via RAPSODI.* Medical Physics, 47(9), 4177–4188, 2020.

# Forecasting Future Anatomies: Longitudinal Brain MRI-to-MRI Prediction

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## Abstract

Predicting future brain state from a baseline magnetic resonance image (MRI) is a central challenge in neuroimaging, with important implications for studying neurodegenerative diseases such as Alzheimer's disease (AD). Most existing approaches predict future cognitive scores or clinical outcomes, such as conversion from mild cognitive impairment to dementia. Instead, we investigate longitudinal MRI image-to-image prediction that forecasts a participant's entire brain MRI several years into the future, intrinsically modeling complex, spatially distributed neurodegenerative patterns.

We implement and evaluate five deep learning architectures (UNet, $U^2$-Net, UNETR, Time-Embedding UNet, and ODE-UNet) on two longitudinal cohorts (ADNI and AIBL). Predicted follow-up MRIs are directly compared with actual follow-up scans using metrics that capture global similarity and local differences. The best performing models achieve high-fidelity predictions, with $U^2$-Net obtaining the highest structural similarity (SSIM=0.990, PSNR=31.32 dB) and ODE-UNet excelling at longitudinal change prediction ($\Delta$-Pearson=0.253). All models generalize well to an independent external dataset, demonstrating robust cross-cohort performance.

Our results indicate that deep learning can reliably predict participant-specific brain MRI at the voxel level, offering new opportunities for individualized prognosis and understanding of brain aging trajectories in neurodegenerative disease.

# Simulator for low-field MRI

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## Abstract

Magnetic Resonance Imaging (MRI) is a widely used medical imaging technique in hospitals and in veterinary medicine. However, most clinical MRI machines require expensive superconducting magnets. Low-field MRI (LF-MRI) offers low-cost alternative but it suffers from worse image quality due to the reduced signal-to-noise ratio and main field inhomogeneities. The goal of this work is to develop a simulation program suitable for LF-MRI which we can use as an accurate forward model for the development of model-based image reconstruction methods.

The simulator is designed to be as physically accurate as possible accounting for both main field inhomogeneities and anisotropies in the spin dynamics. Gradient and RF coils are also modelled to account for all non-idealities. Other components of the simulator include the models of the MRI system, including electronics and signal processing. All components of the simulator have modular design, allowing for easy model switching. The simulator has been implemented in Matlab and it has parallelization support to speed up the simulation.

We tested the simulator with a digital brain phantom and using standard MRI sequences, such as TSE and EPI sequences. Results were mostly similar to what is expected to be seen in real MRI images but more sophisticated validation is still required. However, some sequences, such as UTE, had poor image quality due to the too sparse voxel discretization compared to the amplitude of spoiler and crusher gradients. Later, we will test compare the simulator results with an actual LF-MRI machine to validate the simulator.

# Advanced Data Analysis of Non-proton Metabolic Magnetic Resonance Imaging

Shubo Yan [1], Mikko Kettunen[1], Ekaterina Paasonen[1], Ville Kolehmainen[2]

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## Abstract

Medical imaging plays a key role in modern patient management. Metabolic imaging can reveal metabolic alterations underlying many diseases. Magnetic resonance-based metabolic imaging could make this approach more widely available. The aim of the PhD thesis project is to develop more efficient 5D (3*spatial, spectral and temporal) modeling and denoising methods to maximise the information content in a reasonable imaging time. The methods studied in the project will be tested not only with synthetic data but also with pre-clinical in vivo experiments. The developed methods can be also translated to clinical use.

Sub-study 1: Comparison of Existing Techniques (subspace, tensor, low-rank...) for Denoising of Deuterium Metabolic Imaging (DMI) and Hyperpolarised 13C-images on Simulated and Experimental Data.

Sub-study 2: Deep learning-based metabolic imaging analysis method for Deuterium Metabolic Imaging (DMI).

Sub-study 3: Enhancing Dynamic Nuclear Polarization (DNP) Imaging with Anatomical Priors and Deep Learning: Development and Validation Using In Vivo Data.

# A Dirichlet-to-Neumann map-based model reduction framework for three-dimensional electrical impedance tomography

Fatemeh Maleki Almani, Marko Vauhkonen and Jari Kaipio

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## Abstract

Electrical Impedance Tomography (EIT) is a non-invasive imaging technique with significant potential in industrial and medical applications; however, full three-dimensional models utilized in this study are often computationally expensive. As an example in a cylindrical pipeline geometry, the computational domain can be divided into multiple regions to improve efficiency. The outer sections of the domain are replaced by Dirichlet-to-Neumann (DtN) operators, resulting in a reduced model that preserves the boundary effects while concentrating the computations on the central region. The reduced model is then employed within an inverse problem framework to estimate the unknown conductivity parameters from boundary measurements.

The results show that the DtN map-based model provides a close approximation to the full solution while significantly reducing computational cost. This approach offers a promising pathway toward faster and more efficient three-dimensional EIT for applications in both medicine and industry, such as flow monitoring, process control, and medical imaging tasks including human chest imaging. This work is carried out in collaboration with Rocsole company.

# End-to-end electrical impedance tomography: custom sub-second hardware and lightweight neural networks

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## Abstract

Current clinical protocols for brain hemorrhages rely on initial MRI or CT scans to determine anomaly size and position. However, there is a critical lack of continuous, real-time monitoring to alert physicians if a patient's condition worsens. Electrical Impedance Tomography (EIT) offers a promising pathway toward a non-invasive, 24/7 wearable monitor. Small neural networks have shown the ability to process EIT measurements in real time with minimal errors while remaining feasible to run on energy-efficient embedded hardware. To train these networks, one must collect massive amounts of training data, thereby raising the need for a high-speed EIT data collection system.

To address this, an end-to-end EIT measurement system optimized for high-throughput data collection is being developed. Unlike traditional systems that rely on resource-heavy AC sampling, this custom hardware is largely frequency-agnostic. It utilizes analog temperature-compensated rectification to DC, significantly reducing ADC processing requirements. The current 8-electrode prototype cycles through all injection pairs, achieving a frame rate of 40 fps with a 14-bit equivalent resolution.

This sub-second speed enables the rapid collection of large datasets (e.g., 50k–100k measurements) to train NNs for the EIT inverse problem. Preliminary synthetic data tests show that lightweight architectures—ranging from MLPs to Transformers—can isolate critical variables like hemorrhage size while ignoring unimportant spatial variations.

Following feasibility studies on synthetic data, a fully functional first prototype of the measurement system has been built, and experimental validation on a 2D physical phantom is currently underway. While the primary target is a scalable 3D head phantom for medical monitoring, the underlying lightweight, multi-frequency (25–250 kHz) architecture is highly adaptable and can be scaled to high-channel counts (e.g., 64–256) for industrial applications, such as underground sensing or aerosol concentration research.

# Patient-Specific Biomechanics in Late-Stage Knee Osteoarthritis: Gait, Load Distribution, and Pain

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## Abstract

Late-stage knee osteoarthritis (KOA) is a whole-joint disease associated with structural and biomechanical changes that can alter internal tibiofemoral load distribution. In collaboration with Kuopio University Hospital, we characterized internal tibiofemoral load distribution in 8 individuals with late-stage KOA and 8 healthy controls using magnetic resonance image-based participant-specific musculoskeletal modeling [1] together with motion capture and gait analysis. The KOA group showed a more pronounced anterior-to-posterior redistribution of tibiofemoral loading impulse compared to healthy controls. Our findings suggest that late-stage KOA is associated with altered internal knee joint loading distribution. Such patient-specific loading measures may provide clinically relevant information for pre-operative total knee arthroplasty planning and post-operative rehabilitation. [1] Esrafilian A et al., IEEE TBME,2025

# Measurement Modalities: Towards Measuring Human Movement Outside the Laboratory

Alexander K. Beattie[1] Matti J. Kortelainen[1]
Paavo Vartiainen[1] Pasi A. Karjalainen[1]

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## Abstract

The modern health and wellness environment presents many unique challenges. The increase in the global elderly population is causing a rise in age-related illnesses and injuries which can decrease overall health and well-being. This research project utilizes musculoskeletal modeling and human motion measurement to understand and analyze a wide range of movements to improve overall health. Through these methods, tailor-made solutions are being developed for estimating and predicting human kinematics and kinetics for personalized medicine and customized prosthetic design and control.

Achieving these goals requires the development of methods for simple and accurate human motion measurement in any environment. For example, estimating ground reaction forces using only wearable sensor data enables dynamics analysis in a wide variety of new environments. Augmenting existing measurement technologies enables decreasing the overall amount of sensors required for motion measurement. These advances will improve the accessibility of biomechanics analysis for everyone by decreasing measurement expense, complexity, and location dependence.

Translating recent laboratory breakthroughs to real, outdoor environments allows us to simply and effectively develop methods to analyze and utilize sensor data in real life. In this project, we are building mathematical, machine learning, and physics-informed methods to create next generation health and biomechanics innovations. These methods will help restore and improve patients' well-being and locomotion abilities which improves their overall quality of life.