STSM REPORT (short scientific report)

STSM Application number: COST-STSM-BM1205-27481

STSM Grantee: Gilad Drozdov (COST-STSM-ECOST-STSM-BM1205-210515-060649)

STSM title: Cross-sectional optoacoustic imaging

Home Institution: Technion – Israel Institute of Technology

Host Institution: Helmholtz Zentrum Institute for Biological & Medical Imaging (IBMI), Technical University of Munich

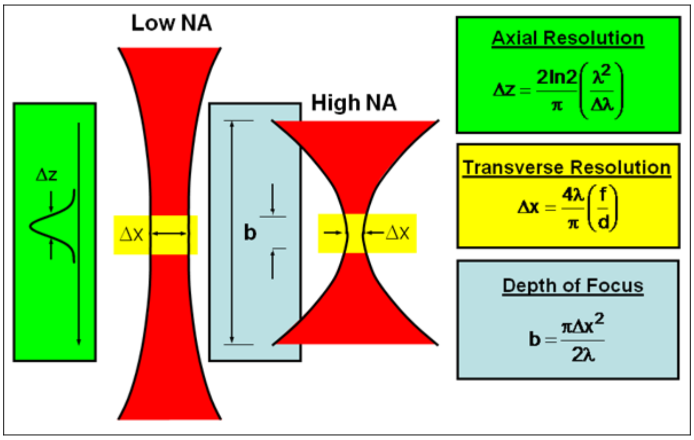
STSM period: 21/05/2015 to 28/05/2015

STSM purpose: The nature of this visit was educational, get familiarized with the activity in the optoacoustic lab, understand how the optoacoustic systems work, and get to see some unique imaging setups that were published by IBMI and evaluate the reconstruction algorithms employed.

Description of the work carried out during the STSM:

Reviewing OAT setups:

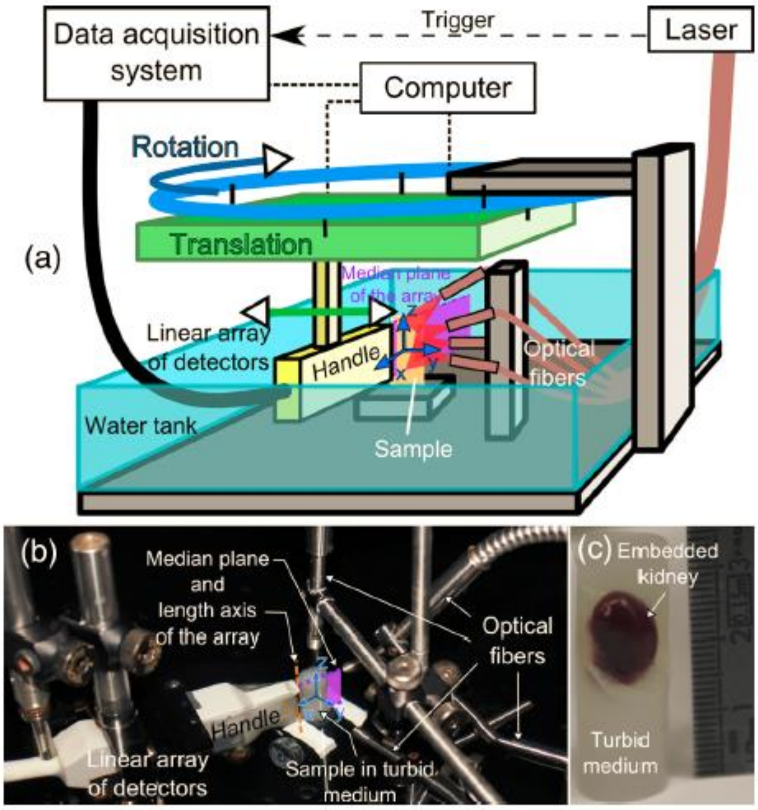
- Raster-scan acoustic resolution broadband optoacoustic mesoscopy system:
  The system is mainly determined by its longitudinal (axial) resolution, transverse resolution, dynamic range (i.e. sensitivity) and data acquisition specifications (laser/scanning method) using a spherically focused detector.



The combination of resolution & imaged volume obtained is new for tomographic optoacoustic mesoscopy, and corresponds to a two-fold improvement in term of resolution at high depths of field in comparison to previous systems. The system can be also used for generating high resolution 3D images

A similar setup also provided tumor vasculature with state of the art in-vivo resolution, using the technique of multi-frequency reconstruction, so that the high frequencies are not masked by low frequencies.

- High-resolution OA mesoscopy with multi-detector translate- rotate scanner:
  We have 3D scan with a spherically focused lens that is shifted and moved with overlapping areas to produce focus over all points meaning we have a long acquisition time. the transducer is of high BW, it's a 3D scan which means a huge portion of data is being used , due to that the reconstruction is made using back-projection (BP), the detector are positioned a 45 degrees to that we will have spherical sampling surface. An illustration from a published paper (A.Chekkoury et al) is presented below (high-frequency linear array and a full-field illumination)



The developed system achieved better than 30 µm in-plane resolution and 110 µm elevation resolution over a cylindrical volume of 9-mm diameter and 9-mm height. Using the implementation of a translate-rotate detection geometry and tomographic reconstruction. The approach yielded images of optically absorbing structures with a level of detail never-before visualized in an intact mouse.
The motivation is to enable this approach for in-vivo imaging using a multi-spectral approach, which will enable us to have functional information (based on the absorption of different tissues at different wave-lengths).

With a multispectral approach, our optoacoustic would allow volumetric localization of different biomarkers within the endogenous contrast distribution and therefore could provide valuable functional information at both macroscopic and mesoscopic scale.

The use of a continuous acquisition regime enables an increase in the number of angular orientations available to tomographic views and reduces the scanning time over averaged acquisition. With continuous acquisition, the scanning time could be reduced by more than a factor of two for similar image quality.

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GPU coding:

- GPU IMMI code is currently implemented using OpenCL, and has a major acceleration in 3D reconstruction (takes days on CPU). The main optimization is calculating the LSQR using the clBLAS, the model-matrix is never stored in memory (due to HW limitations) and the optimization is done over the element multiplication and matrix transpose calculation, without performing profiling. An extension to this work can be the migration of this code to CUDA for the usage of NVIDIA high-performance GPU. By performing profiling we can speed-up the parts of the currently slow calculations.

Data acquisition:

- Falkenstein data acquisition module: similar setup will be assembled in the Technion lab, during this visit we have performed a full scanning procedure with an OAT equipment, sampled the signals and performed reconstruction (using a hybrid SW). This will contribute greatly to conduct such experiment at the Technion.

- Collection of experimental data of both phantoms and in-vivo /ex-vivo animal scanning. This data will enable to establish the quality of the reconstruction algorithms developed at the Technion.

Description of the main results obtained:

- Familiarize with lab equipment and setups *(in vivo / ex vivo*), which will contribute to the bring-up of the lab at the Technion.
- Evaluation of Experimental protocols (MATLAB) for different systems.
- Review of reconstruction schemes, the backprojection (BP) method is used widely (for most of the setups) due to its advantages in runtime, however the model-based approach can yield better image quality, this gives motivation for our work of acceleration of the reconstruction algorithms using wavelet packets (WP).
- Transducer geometry analysis: different setups use different detectors (in respect to main frequency, shape and size) the tradeoffs associated with each detector geometry are not fully understood, the benefit of design rules to determine the best geometry for a given imaging scenario can bring added value and improve reconstruction results.

- Experiment protocol implementation using MATLAB which is used to control stages of data acquisition and collect the acoustic data for multi-channel transducer systems.

- Wavelet packet frame work evaluation for model-based reconstruction: the current method extract the relevant frequency bands by using a global threshold (based on the maximum eigenvalues of the SVD decomposition) there is a motivation to explore other conditions to improve the quality of reconstruction (for example a separate condition for each band).

Mutual benefits for the Home and Host institutions:

- Gaining hands-on expertise with OAT equipment (data acquisition), set-up topologies and experimental protocols will have a great contribution to the bring-up of similar setups at the emerging lab at the Technion for real-word data acquisitions.

- Data Sharing: the captured acoustic data of *in vivo* experiments is of great value, as it is needed to validate the quality of reconstruction. The collected data is captured in sophisticated setups and different targeted objects (mice, fish etc.).

- Code sharing: the acceleration of model-based reconstruction algorithms is of great value, due to its better performs in image quality. IBMI has successes to accelerate the 2D and 3D reconstruction algorithms using GPU coding. A mutual effort will be done accelerating the wavelet packet model-based scheme that should give much better performance results, can be used for reconstruction in real setups at IBMI and Technion.

- Investigating the effect of detector geometry on the characteristics of reconstruction at the Technion aims to understand the tradeoffs associated with each detector geometry and offer design rules which will determine the best geometry for a given imaging scenario, which can be used in both IBMI and Technion experimental trails.

Future collaboration with the Host institution:

Real-time image reconstruction:

The ability of real-time image reconstruction is crucial in numerous scenarios, and is a pre-condition for all clinical practice. Real-time tomography system based on the model-based methods (developed at IBMI) are currently under development and use advanced GPU hardware with sophisticated parallel coding, collaboration in efficient algorithms implementation of reconstruction methods is a major step in the maturation of this imaging modality for clinical practice.

Analysis tools:

The fundamental difference in image characteristics is depend on the geometrical (and other attributes of the system) properties of the transducers and yet not fully understood. Our model simulations will enable to perform analysis under the wavelet-packet (WP) framework, for a variety of detector geometries and hopefully will provide the recipe for a setup formulation that will enhance image quality by determining the best geometry for a given imaging scenario.

TV based methods for reconstruction:

Regularization based on TV methods for image reconstruction, IBMI is currently conducting TV-based regularization for image reconstruction (instead of commonly used Tikhonov), we suggest to use higher order of variational regularization (TGV) of second order (

$$TGV_\alpha^2 = \min_\upsilon \left\{ \alpha_1 \int_\Omega |\nabla u - v| dx + \alpha_0 \int_\Omega |\nabla v| dx \right\}$$

TGV promotes an affine piece-wise solution, which is suitable for a type of images, which can be thought of as a combination of several planar surfaces with sharp discontinues between them, which produces sharp-edge preserving image.

A Spectral Approach to TV for Image Reconstruction:

The model-based approach using the Wavelet-Packets (WP) which have been developed in IBMI allows for quality reconstruction with a considerable reduction in run time and memory, and allows for analysis of the reconstruction for different image construction and setup. The main drawback is the fact that different bands (WP leafs) have overlapping frequencies. The TV-spectral approach developed at the Technion allows for image scale/texture separation, and might give added values to a signal decomposition/ reconstruction uses this basis.

STSM outcome form

STSM application number	Home institution & country	Host institution & country	BM1205 WG	Objective of the collaboration	Results of the collaboration
COST-STSM-ECOST-STSM-BM1205-210515-060649	Technion – Israel Institute of Technology, Haifa Israel.	Helmholtz Zentrum Institute for Biological & Medical Imaging, Munich Germany	WG1 - COST-STSM-BM1205 European Network for Skin Cancer Detection using Laser Imaging	Educational training activities in cross-sectional optoacoustic imaging	- Evaluation of Experimental protocols, and experimental systems with respect to detector geometry. - Application of image reconstruction algorithms & data analysis focusing on model-based schemes. - Reconstruction acceleration using GPU coding for model-based algorithms. - Wavelet packet analysis for model-based scheme (extend the work for other geometries).

Confirmation of the host institution on the successful completion of the Short-Term Scientific Mission

To the Grant Holder of the COST Targeted Network COST-STSM-BM1205
Place, date: München, 11 June 2015
The host institution
Technische Universität München, Chair for Biological Imaging
hereby confirms the successful completion of the STSM stay of [name of applicant]
Gilad Drozdov from 21 May '15 to 28 May '15.

Yours sincerely,
First name and last name:
Prof. Vasilis Ntziachristos
Signature:

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