Challenges of 4D Photoacoustic Tomography

Elevator Pitch @ Challenges in Dynamic Imaging Data

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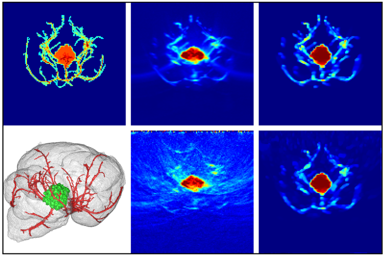
joint with: Marta Betcke, Simon Arridge, Ben Cox, Nam Huynh, Edward Zhang and Paul Beard



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Dynamic High Resolution Photoacoustic Tomography

PAT based on Fabry Perot (FB) interferometer:

- ✓ high spatial resolution
- ✓ high sensitivity
- ! low temporal resolution
- ! restricted to planar geometries

Sub-sampling each frame i:

$$f_i^c = G_i f_i = G_i(Ap_i + \varepsilon_i)$$

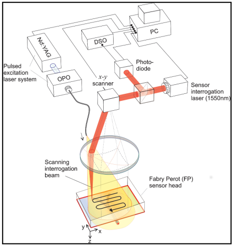
Image reconstruction:

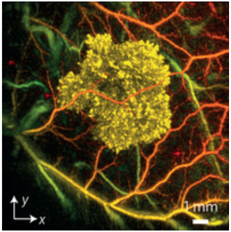
$f_i^c \longrightarrow f_i$, $f_i \longrightarrow p_i$ by standard method.

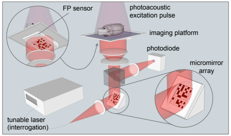
$f_i^c \longrightarrow p_i$: standard or new method?

$F^c \longrightarrow F$, $f_i \longrightarrow p_i$ by standard method.

$F^c \longrightarrow P$: Full spatio-temporal method.





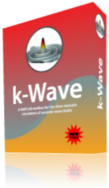


Standard PAT Image Reconstruction

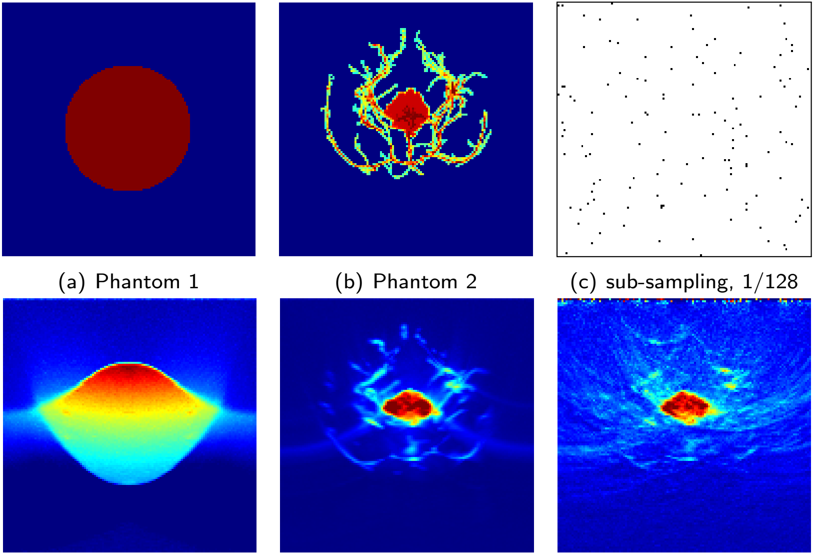
Eigenfunction expansion and closed-form filtered-backprojection approaches are too restrictive for us (similar to CT).

Time Reversal (TR):

- "Least restrictive PAT reconstruction"
- Sending the recorded waves "back" into volume.
- Requires a numerical model for acoustic wave propagation.
- **kWave**$^{(*)}$ implements a k-**space pseudospectral method**.



$^{(*)}$B. Treeby and B. Cox, 2010. *k-Wave: MATLAB toolbox for the simulation and reconstruction of photoacoustic wave fields*, *Journal of Biomedical Optics*.



(a) Phantom 1 (b) Phantom 2 (c) sub-sampling, 1/128

(d) TR recon 1 (e) TR recon 2 (f) TR recon, 1/128

Planar sensor on top, $n = 128^3$, SNR: 10. Maximum intensity projections, side view

Variational Approaches, Matrix Formulation

Solving variational regularization problems

$$\hat{p}_\lambda = \underset{p}{\operatorname{argmin}} \left\{ \tfrac{1}{2} \|Ap - f\|_2^2 + \lambda \mathcal{J}(p) \right\}$$

by first-order methods such as proximal gradient algorithm or ADMM requires a numerical representation of A and A^T.

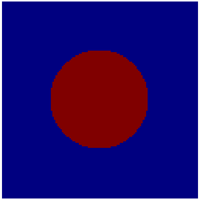
All the steps of the numerical iteration to solve of the direct problem can be combined to a linear operator

$$f = Ap$$

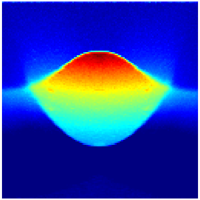
Then, one can derive a numerical adjoint iteration to have a numerical representation of A^T (extremely tedious work, cf. [1]).

[1] C. Huang, K. Wang, L. Nie, L.V. Wang, M.A. Anastasio, 2013. *Full-Wave Iterative Image Reconstruction in Photoacoustic Tomography With Acoustically Inhomogeneous Media*, *IEEE Transactions on Medical Imaging*.

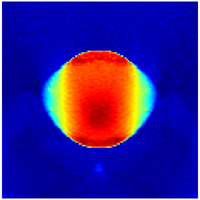
Comparison for Full Data



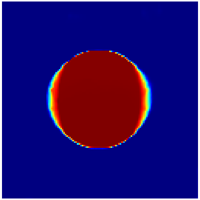
(a) Phantom 1



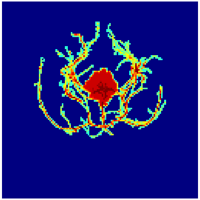
(b) TR recon 1



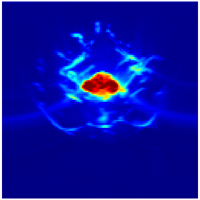
(c) PI^+



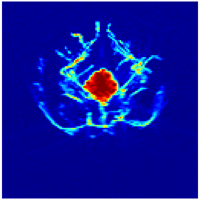
(d) TV^+



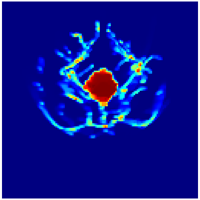
(e) Phantom 2



(f) TR recon 2



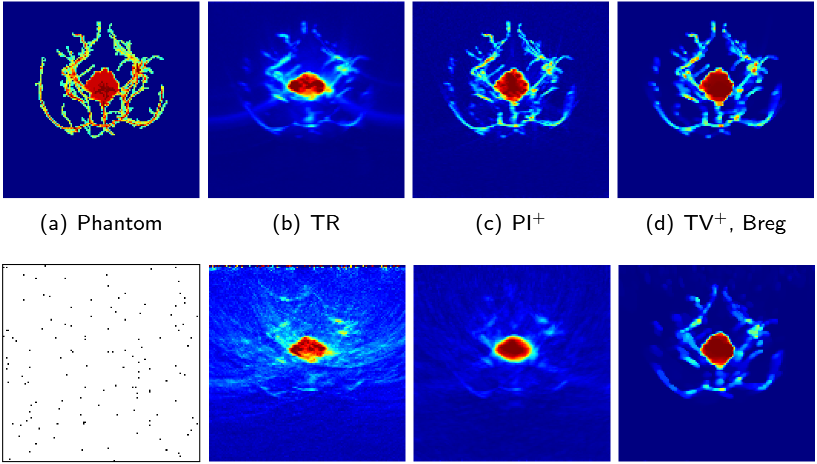
(g) PI^+



(h) TV^+, Breg

Planar sensor on top, $n = 128^3$, SNR: 10. Maximum intensity projections, side view

Comparison for Sub Sampled Data

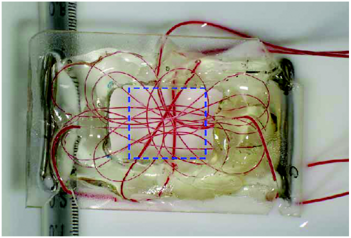


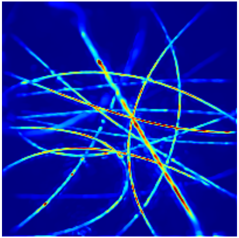
(a) Phantom (b) TR (c) PI^+ (d) TV^+, Breg

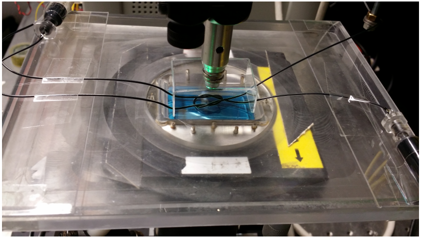
(e) Sub, 1/128 (f) TR (g) PI^+ (h) TV^+, Breg

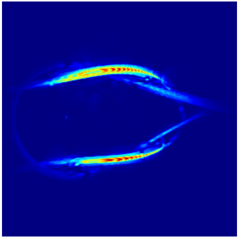
Planar sensor on top, $n = 128^3$, SNR: 10. Maximum intensity projections, side view

Leaving the Comfort Zone: Reproduction on Real Data





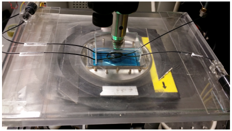


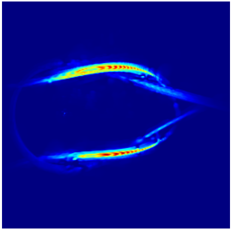


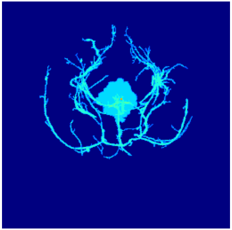
Current problem: Model fit seems insufficient.

- Suitable pre-processing.
- Refine/calibrate forward model.

Outlook: Spatio-Temporal Reconstruction







Continuous data acquisition

$\Longrightarrow$ tradeoff between spatial and temporal resolution.

Different dynamic models:

- Low-Rank (functional imaging with static anatomies).
- Low-Rank + sparsity.
- Tracer uptake models.
- Perfusion models.
- Optical flow constraints for joint image reconstruction and motion estimation.

Thank you for your attention!

Poster: *Dynamic High Resolution Photoacoustic Tomography*

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