Tensor-based Multi Spectral Computerized Tomography Method for Energy Resolved Imaging and Material Characterization

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Abstract

We present a novel polychromatic multi energy computed tomography (CT) processing method that may be helpful in material characterization. Energy selective reconstructions are possible due to the use of photon counting detectors which allow measurements in energy bins. We interpret the problem as a multi spectral imaging one and provide a tensor-based formulation and iterative reconstruction of the linear attenuation coefficient as well as a regularization technique based on low rank assumptions. The method is compared with filtered back projection (FBP) and with an iterative reconstruction method that uses total variation (TV) regularization for measurements at each energy bin separately. The algorithm returns results in reasonable computation time, therefore the algorithm can be implemented on a real CT scanner.

Relevance

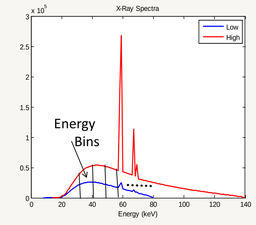
- ❑ Filtered Back Projection (FBP) approaches are prone to fail in the presence of noise in the data [1] and for limited view acquisition geometries.
- ❑ Iterative algorithms provide the opportunity to take into account the statistical properties of X-ray interactions, the noise and arbitrary data acquisition scenarios.
- ❑ The multi energy CT is already an active research area that finds application in medical imaging [4] and airport security.
- ❑ Here, we exploit the flexibility of an iterative variational approach and tailor an algorithm that exploits the multispectral nature of the problem.
- ❑ The state of art [6] for the luggage screening problem suffers from artifacts which can prevent accurate detection of explosives.
- ❑ Iterative reconstruction algorithms, such as the one presented here, are promising alternatives towards the goal of reducing the error rate in the detection explosives and other illicit materials.

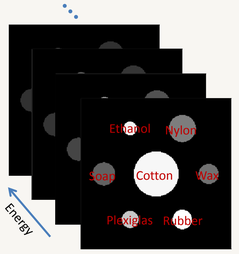
Technical Approach

- Assumption of perfectly resolved energy bins leads to a series of linear inverse problems:

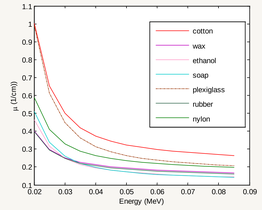
$\mathbf{K}\mathbf{x}_i = \mathbf{m}_i \quad \text{for} \quad i = 1,\ldots,N_E$

where N_E is the number of energy bins and $\mathbf{x}_i$'s are the unknown attennuatio coefficient vectors.



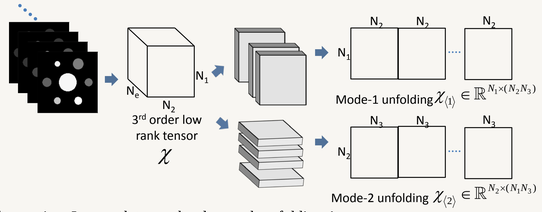


Similarities of images in different energies lead to a low rank tensor structure

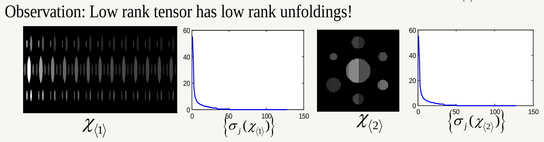


Correctly reconstructed attenuation curves may lead to material characterization

- Hard to optimize rank of tensor itself.
- Easy to work with its unfoldings:



- Observation: Low rank tensor has low rank unfoldings!



$X \in \mathbb{R}^{N_1 \times N_1}, \quad m = \min(N_1, N_2)$

Nuclear (trace) norm $:= \|X\|_* = \sum_{j=1}^{m} \sigma_j(X)$

- Favors zero singular values, hence low rank matrices
- Intuitively : L1 Regularization of singular values
- For the Multi energy CT problem, regularization via nuclear norm of all the unfoldings :

$$R_{\text{nuc}}(\mathcal{X}) = \sum_{j=1}^{\dim(\mathcal{X})} \left\| \mathcal{X}_{\langle j \rangle} \right\|_*$$

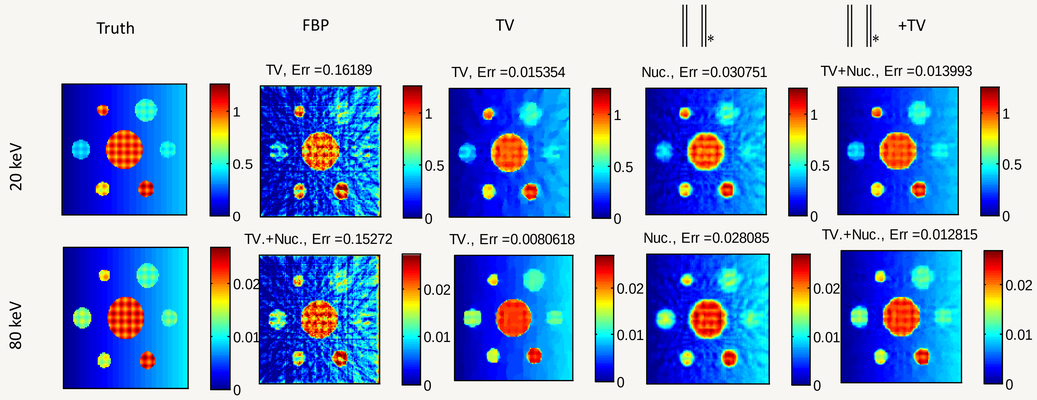
- We can solve the multi energy CT problem with avariational approach:

$$\hat{\mathcal{X}} = \underset{\mathcal{X} \in \mathbb{R}^{N_1 \times N_2 \times N_E}}{\operatorname{argmin}} \underbrace{\frac{1}{2}\left\| K(\mathcal{X}) - m \right\|^2}_{\text{Data mismath}} + \underbrace{\lambda_1 \sum_{j=1}^{\dim(\mathcal{X})} \left\| \mathcal{X}_{\langle j \rangle} \right\|_*}_{\text{Nuclear Norm Regularizer}} + \underbrace{\lambda_2 TV(\mathcal{X})}_{\text{Optional TV Regularizer}}$$

- Convex optimization problem can be solved via Alternating Direction Method of Multipliers (ADMM):

$$\begin{aligned} \underset{\mathcal{X},\mathcal{Z}}{\text{minimize}} \quad & \frac{1}{2}\left\| K(\mathcal{X}) - m \right\|^2 + \lambda_1 \sum_{k=1}^{\dim(\mathcal{X})} \left\| Z_k \right\|_* + \lambda_2 TV(\mathcal{X}) \\ \text{subject to} \quad & \mathcal{X}_{<k>} = Z_k, \quad k = 1,\ldots,\dim(\mathcal{X}) \end{aligned}$$

- Parallel beam measurements with 20 dB additive Gaussian noise uniformly distributed16 angles around the medium
- Some texture is added to the phantom (128x128 Pixels) for more realistic ground truth
- Measurements are performed for 12 energies in 20 – 80keV range



Accomplishments Through Current Year

- ❑ Novel multi energy CT reconstruction algorithm is developed
- ❑ The promises and advantages of the multi energy CT systems in the airport security platform are investigated

Future Work

- ❑ Seek collaboration with vendors to test the algorithm in real scanners and evaluate its feasibility.
- ❑ Statistical properties of the photon counting detectors can be incorporated to the current method for better performance
- ❑ Extension of current approach for specifically detecting explosives might be possible.

Opportunities for Transition to Customer

- ❑Simulation examples demonstrate the advantages of the proposed method.
- ❑Accurate material characterization may be possible via multi energy CT.
- ❑ The applicability of the proposed method can be investigated by testing the method on real life scanners.
- ❑ Increasing the probability of detection of explosive type objects significantly enhances security.
- ❑ By providing accurate material characterization the false alarm rate would decrease which in turn would increase efficiency of the aviation screening process.

Publications Acknowledging DHS Support

[1]O. Semerci, E. Miller, "A Parametric Level Set Approach to Simultaneous Object Identification and Background Reconstruction for Dual Energy Computed Tomography", IEEE Transactions on Image Processing (accepted, preprint available at IEEE).

[2]E. Miller, O. Semerci, "A hybrid approach to imaging and anomaly characterization from dual energy CT data," In Proc. SPIE Conference on Computational Imaging IX, San Francisco, CA, January 2011

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Other References

[4]X Wang, D Meier, S Mikkelsen, G E Maehlum, D J Wagenaar, BMW Tsui, B E Patt, and E C Frey, "**MicroCT with energy-resolved photon-counting detectors**," *Phys Med Biol. 2011 May 7; 56(9): 2791–2816*

[5]P. Sukovic, N. H. Clinthrone, J.A. Fessler, I. Elbakri, "Maximum-likelihood dual-energy tomographic image reconstruction," *SPIE Med. Imag., vol. 4684, no. 2, pp. 38-49, 2002.*

[6]Z. Ying, R. Naidu, and C. Crawford, "Dual energy computed tomography for explosive detection," *J. of X-ray Sci. and Tech., vol. 14, no. 4, pp. 235-256, 2006.*

This material is based upon work supported by the U.S. Department of Homeland Security under Award Number 2008-ST-061-ED0001 . The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied of the U.S. Department of Homeland Security.