Classification-aware methods for explosives detection using multi-energy X-ray computed tomography

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Motivation

- In luggage inspection, **higher detection accuracy** and **lower false alarm rates** are needed.
- **Multi-Energy X-ray Computed Tomography (MECT)** is a non-destructive scanning technology with the potential for enhanced material discrimination.
- Through the principled application of **machine learning and optimization methods**, significant improvement of existing MECT systems may be obtained.

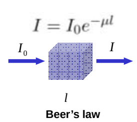
Our focus:

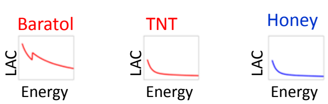
Optimizing information extraction from MECT measurements for increased discrimination between explosive and benign materials

Physical Model

Materials and X-rays: The LAC

- X-ray interaction with materials captured by the Linear Attenuation Coefficient (LAC): μ
- Function of X-ray energy
- Material "signature"
- MECT measurements contain LAC info.





- Assumption: $\mu(E) = \sum_{i=1}^{N} a_i f_i(E)$

material-specific coefficients; known energy-dependent basis functions

- A common **physics-based representation** is [1]:

$$\mu(E) = a_P f_P(E) + a_C f_C(E)$$

Photoelectric effect; Compton scatter

- The problem: **photo-Compton model does not fit all materials and is not tuned for classification**.

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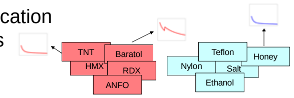
Basis Selection Methods

- View problem as binary classification: explosive vs. benign
- Use labeled data
- Find basis functions f_i tuned for classification
- Use resulting coefficients a_i as features



Data:

- Sampled LAC-curves of materials (124 explosives and 111 non-explosives [2-6])

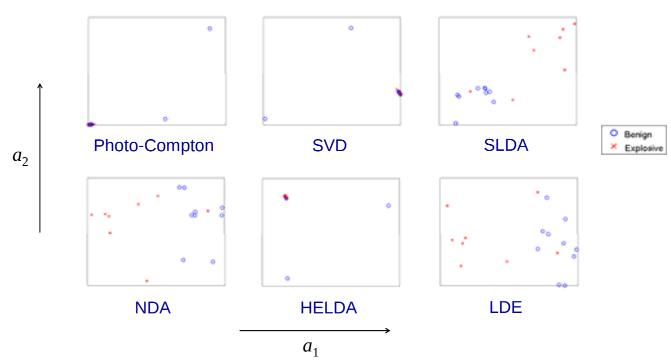
Methods examined:

- Photo-Compton model (Photo-Compton)
- Singular Value Decomposition (SVD) [7]
- Sequential Linear Discriminant Analysis (SLDA) [8]
- Non-parametric Discriminant Analysis (NDA) [9]
- Heteroscedastic Extension of Linear Discriminant Analysis (HELDA) [10]
- Local Discriminant Embedding (LDE) [11]

Method	Adaptive?	Classification-aware?
Photo-Compton	x	x
SVD	✓	x
SLDA	✓	✓
NDA	✓	✓
HELDA	✓	✓
LDE	✓	✓

2D Example

- Chose randomly 10 explosives and 10 benign materials to compose example dataset
- For each basis selection method:
  - Obtained basis functions f_1 and f_2
  - Calculated the corresponding coefficients a_1 and a_2 for each of the materials in the dataset

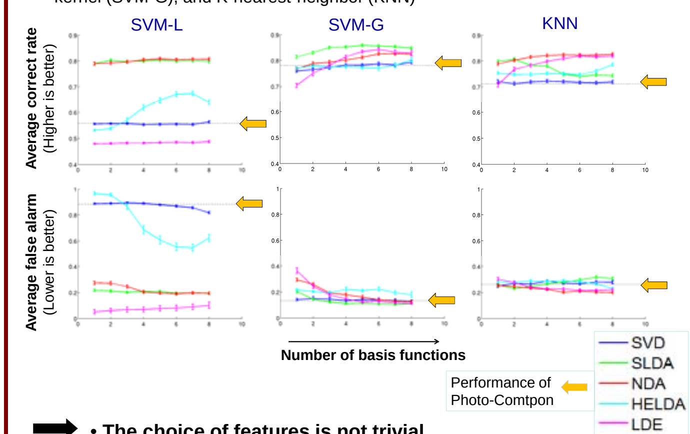


➡ **Separability is higher using classification-aware methods.**

Average Classification Performance

- Evaluated basis selection methods by classifier performance
- The experiment:
  - Step 1: Divide data randomly into training (80%) and testing (20%)
  - Step 2: Apply basis selection methods to training data to obtain basis fns f_i
  - Step 3: Train the classifier using coefficients a_i of the training data
  - Step 4: Test the classifier using coefficients a_i of the test data
  - Step 5: Repeat steps 1-4 and calculate average correct rate

We used three classifiers: SVM with linear kernel (SVM-L), SVM with Gaussian kernel (SVM-G), and K-nearest-neighbor (KNN)

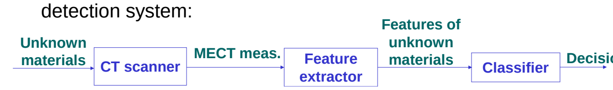


➡ **The choice of features is not trivial.**

- **It is possible to do better than with photo-Compton.**
- **It is possible to do better than with just 2 coefficients.**

Research to Reality

Results of this study may lead to an improved CT based explosive detection system:



Next step: Incorporating the basis selection procedure into the complete MECT problem.

References:

[1] R. E. Alvarez and A. Macovski, Energy-selective reconstructions in X-ray computerized tomography, Physics in medicine and biology 21 (5), pp. 733-744, 1976.
[2] M.J. Berger et al., XCOM: Photon Cross Section Database, National Institute of Standards and Technology.
[3] B. Dobratz and P. Crawford, LLNL Explosives Handbook, 1985.
[4] URI explosives database, 2008.
[5] J. Akhavan, Chemistry of Explosives 2nd ed., Royal Society of Chemistry, 2004.
[6] The European Synchrotron Radiation Facility (ESRF) Scientific Software, 2008.
[7] G. Golub and C. Reinsch, Singular value decomposition and least squares solutions, Numerische Mathematik 14, pp. 403–420, 1970.
[8] D.H. Foley and J.W. Sammon, An Optimal Set of Discriminant Vectors, IEEE Trans. Comput., vol.C-24, no.3, pp. 281- 289, 1975.
[9] K. Fukunaga and J.M. Mantock, Nonparametric Discriminant Analysis, IEEE Trans. Pattern Anal. Machine Intell., vol.PAMI-5, no.6, pp.671-678, 1983.
[10] R.P.W Duin and M. Loog, Linear dimensionality reduction via a heteroscedastic extension of LDA: the Chernoff criterion, IEEE Trans. Pattern Anal. Machine Intell., vol.26, no.6, pp.732-739, 2004.
[11] H.-T. Chen et al., Local discriminant embedding and its variants, Proc. IEEE Conf. Computer Vision and Pattern Recognition, pp. 846- 853 vol. 2, 2005.