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

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Abstract

X-ray Computed Tomography (CT) is a powerful non-destructive technology used for baggage inspection. CT imaging is based on the X-ray attenuation of the scanned materials. In Multi-Energy Computed Tomography (MECT), multiple energy-selective measurements of the X-ray attenuation can be obtained. This provides more information about the chemical composition of the scanned materials than single-energy technologies and potential for more reliable detection of explosives.
We study the problem of discriminating between explosives and non-explosives using features extracted from the X-ray attenuation versus energy curves of materials. The features commonly used in conventional (dual-energy) systems are the photoelectric and Compton coefficients, which are based on an approximate physical model. We demonstrate that the detection performance can be improved by using different features obtained via classification-aware learning-based methods. The new approach can be incorporated in existing scanners and can also aid in the design of future multi-energy systems.

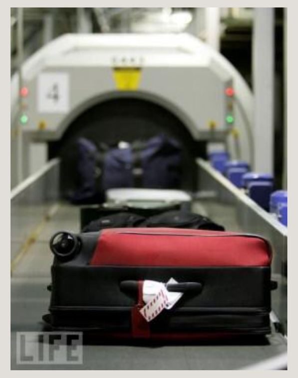
Relevance

Existing approaches:

- Identification (vs. discrimination)
- Two feature material representation [1]
- Dual-energy machines

New approach:

- Discrimination-optimized representations
- Multi-dimensional features
- Multi-energy sensing



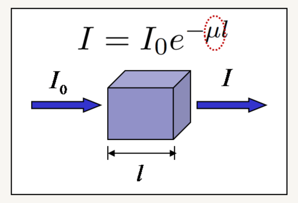
Advancing the state of the art:

- Potential for significant improvement of detection
- Applying machine learning and information theoretic methods to X-ray based explosives detection
- Understanding fundamental limits of existing and future MECT systems
- Optimizing information extraction from MECT measurements for increased discrimination between explosive and benign materials

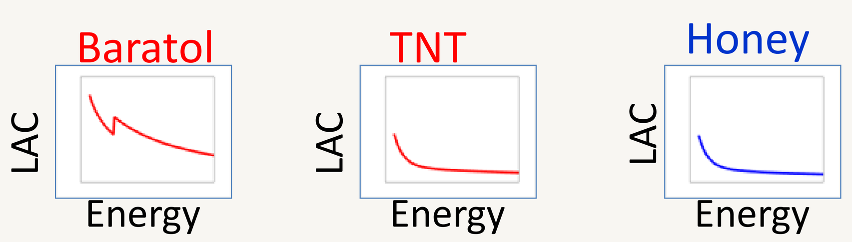
Technical Approach

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.

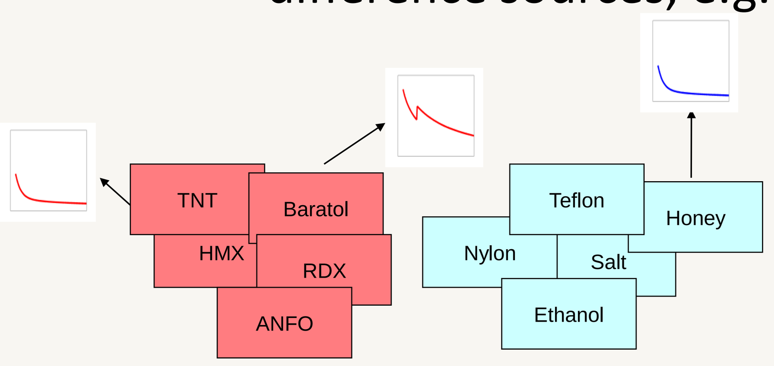


Beer's law



Compounds dataset

- Sampled LAC-curves of materials
  141-dimensional vectors
  124 explosives and 195 non-explosives from difference sources, e.g. [2,3])



Classification-aware methods

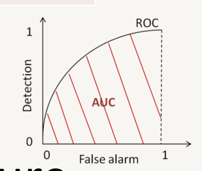
- View problem as **2-class classification**: explosive vs. benign
- Use labeled data
- Find basis functions f_i tuned for classification
- Use resulting coefficients a_i as **features**

Methods examined

- Photo-Compton model (PhCo)
- Singular Value Decomposition (SVD) [4]
- Sequential Linear Discriminant Analysis (SLDA) [5,6]
- Non-parametric Discriminant Analysis (NDA) [7]
- Local Discriminant Embedding (LDE) [8]
- Energy-level selection with ROC criterion (EnLR)

Method	PhCo	SVD	SLDA	NDA	LDE	EnLR
Adaptive?	x	✓	✓	✓	✓	✓
Classification-aware?	x	x	✓	✓	✓	✓

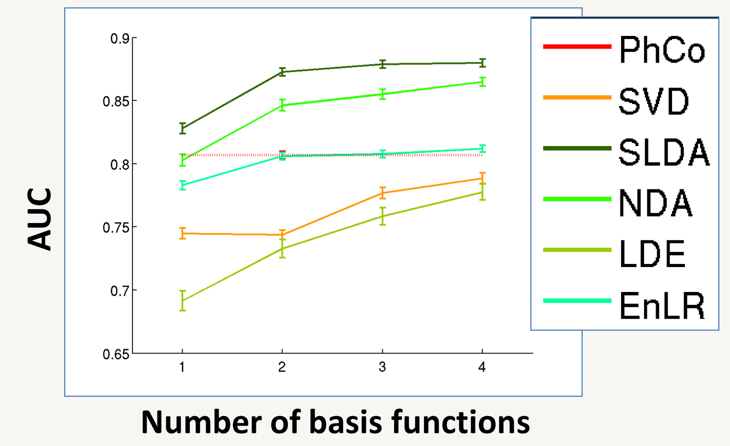
Methods evaluation

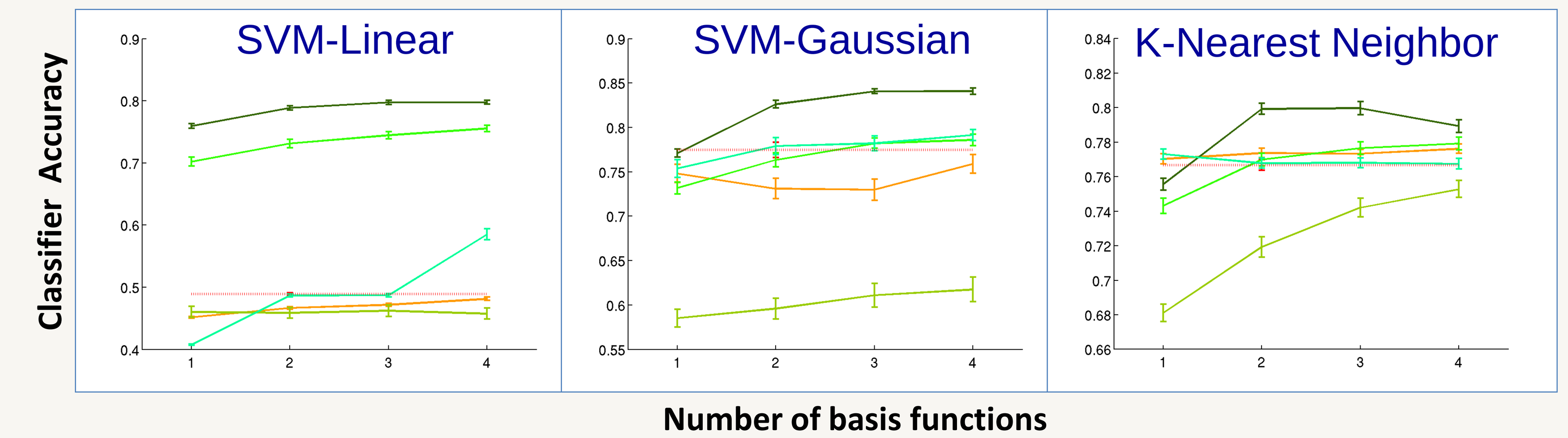


- **Area Under the Receiver Operator Characteristic (AUC)** - fundamental measure of class separability, independent of classifier
- **Classifier Accuracy** – correct classification rate of three different classifiers

Experiment and results

Step 1: Divide data randomly into training (50%) and testing (50%)
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: Calculate AUC using coefficients a_i of the test data
Step 5: Test the classifier using coefficients a_i of the test data
Step 6: Repeat steps 1-5 100 times and calculate average AUC and Classifier Accuracy





Observations

- AUC results indicate detection can be enhanced by using **more than two** multi-energy features and when using **classification-aware** features.
- Finding a specific classifier able to exploit the information in the features is challenging.

Accomplishments Through Current Year

- Fundamental study of materials LACs
- LAC dimensionality greater than 2 -> more than two energies are needed
- Material discrimination can be improved by using features different than the standard photoelectric and Compton coefficients.
- The use of leaned classification-aware feature extraction methods for MECT can increase detection performance and reduce false alarm rates.

Future Work

Incorporation of the complete MECT observation model:

- Reliable reconstruction of classification-aware features
- Understanding the relative reliability/contribution of various energy components
- Understanding the impact of differential absorption

Opportunities for Transition to Customer

- New discrimination optimized representations can be used in place of existing conventional representations to enhance existing systems.
- Understanding of fundamental limits to discrimination can serve as benchmark for evaluation of candidate systems.
- New results can inform the design of next generation MECT systems and estimation algorithms.

Publications Acknowledging DHS Support

- L. Eger, P. Ishwar, W. C. Karl, and H. Pien, "Classification-aware Methods for Explosives Detection using Multi-Energy X-ray Computed Tomography," Research and Industry Collaboration Conference, Oct 2011.
- Eger, L., Do, S., Ishwar, P., Karl, W., and Pien, H., "Study of Material Discrimination Using Multi-Energy X-Ray Computed Tomography for Explosives Detection," The DHS Science Conf. – Fifth Annual University Network Summit, Student Day, March 29, 2011.
- Eger, L., Do, S., Ishwar, P., Karl, W., and Pien, H., "Alearning-based approach to explosives detection using multi-energy X-ray computed tomography," Proc. IEEE Conf. Acoust. Speech Sig. Proc., 2011 .
- Eger, L., Ishwar, P., Karl, W., and Pien, H., "Classification-aware dimensionality reduction methods for explosives detection using multi-energy X-ray computed tomography," Proc. SPIE 7873, Computational Imaging, 2011.
- Eger, L., Do, S., Ishwar, P., Karl, W., and Pien, H., "A Learning-based method for explosives detection from multi-energy X-ray computed tomography measurements," CenSSIS RICC, 2010.
- Eger, L., Do, S., Karl, W., and Pien, H., "Implementation of an image-based dual-energy method for explosives detection on real CT data," CenSSIS RICC, 2009.

Other References

[1] R. E. Alvarez and A. Macovski, *Phys. Med. Biol.* 21(5): 733-744, 1976.
[2] M.J. Berger et al., XCOM: Photon Cross Section Database, NIST.
[3] B. Dobratz and P. Crawford, LLNL Explosives Handbook, 1985.
[4] G. Golub and C. Reinsch, Numerische Mathematik 14: 403–420, 1970.
[5] D.H. Foley and J.W. Sammon, *IEEE Trans. Comput.*, C-24(3): 281- 289, 1975.
[6] L. Eger, P. Ishwar, W. Karl, and H. Pien, *Proc. SPIE 7873, Computational Imaging*, 2011.
[7] K. Fukunaga and J.M. Mantock, *IEEE Trans. Pattern Anal. Machine Intell.*, PAMI-5(6): 671-678, 1983.
[8] H.-T. Chen et al., *Proc. IEEE Conf. Computer Vision and Pattern Recognition*, 2: 846- 853, 2005.

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