Implementation of an Image-Based Dual-Energy Method for Explosives Detection on Real CT Data

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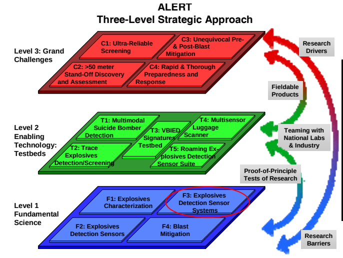


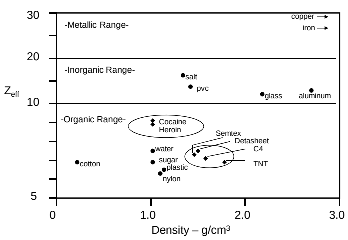
Abstract

X-ray computed tomography (CT) is widely used for medical diagnosis and for security purposes like baggage inspection. CT scanners measure the attenuation coefficient of the scanned object. The attenuation coefficient depends on the material being scanned and is also a function of the energy of the incident x-ray photons. In conventional CT systems the scan is performed with a single source spectrum and it is not possible to determine the chemical composition of the scanned materials. Dual-energy CT is a technology where the object is scanned with two different x-ray spectra. It can be used to estimate the density and the effective atomic number of the object. In the security domain, these numbers along with other features like volume and texture can lead to accurate detection of explosives with low false alarm rate. In the medical domain this information can be used, for example, to improve the differentiation between Iodine filled vessels and other materials in the body.

In this poster we present initial results of applying an image-domain dual-energy algorithm to data obtained by Siemens SOMATOM Definition dual-source CT scanner. The algorithm was proposed by Heismann et. al [1]. As input data the algorithm uses two reconstructed CT images obtained with different source spectra. The output is the density and effective atomic number of the scanned object. This method yields reasonable results for low-atomic-number materials. However, it is insufficient for high atomic numbers. Further work is required to increase the accuracy of the method.

Motivation

- The detection of explosives and illicit material is important for preventing terrorism and smuggling.
- X-ray Computed Tomography (CT) has been the most favorable technology for luggage inspection.
- Higher detection accuracy and lower false alarm rate are needed.
- Dual-energy CT can be used to estimate the effective atomic number, Z_{eff}, and density. These metrics help in identification of explosives.



Z_{eff} and density for common items found in airport luggage and for certain contraband and explosive materials [2]

- In the medical domain, dual-energy CT can add functional information to the morphological information that is usually obtained in a CT examination. The applications are differentiation of iodine from other materials and differentiation between different body tissues.

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Physical model

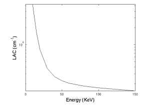
- CT measurements are related to the "**linear attenuation coefficient**" (**LAC**) .
- The LAC of a material depends on the energy of the incident x-ray photons.
- Conventional CT:
  - single polychromatic source spectrum
  - attenuation coefficient is reconstructed at an average energy
  - reconstructed quantity - "**effective attenuation coefficient**" [1]:

$$\bar{\mu} = \int w(E)\mu(E)dE$$

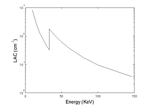
where: $\mu(E)$ - LAC

$w(E) = \frac{S(E)D(E)}{\int S(E)D(E)dE}$ - spectral weighing function

$S(E)$ - source spectra; $D(E)$ - detector response



LAC of **water** as a function of photon energy



LAC of **iodine** as a function of photon energy

Method

- Image-based method for estimating Z_{eff} and density, proposed by Heismann et. al [1].
- Main assumption: Z_{eff} is a function of $\frac{\bar{\mu}_1}{\bar{\mu}_2}$

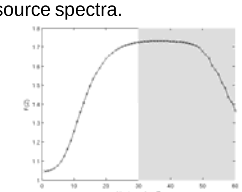
where $\bar{\mu}_1$ and $\bar{\mu}_2$ denote the effective attenuation coefficients produced by two scans with different source spectra.

- Method description:
  - Using known values of the attenuation coefficients [3], calculate in advance the values of the following function:

$$F(Z) = \frac{\bar{\mu}_1}{\bar{\mu}_2} = \frac{f_1(Z)}{f_2(Z)}, \quad Z = 1, \ldots, 30$$

where: $f_i(Z) = \int w_i(E)\left(\frac{\mu(E,Z)}{\rho}\right)dE$

$\frac{\mu(E,Z)}{\rho}$ - mass attenuation coefficient; ρ - density

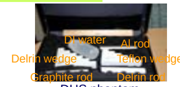


The function F(Z) vs. Z

  - Given two reconstructed images, calculate the inverse function for each pixel by numerical interpolation: $\hat{Z}_{eff} = F^{-1}\left(\frac{\bar{\mu}_1}{\bar{\mu}_2}\right)$
  - Estimate the density by: $\hat{\rho} = \frac{\bar{\mu}_1}{f_1(\hat{Z}_{eff})}$

Experiment with Real CT Data

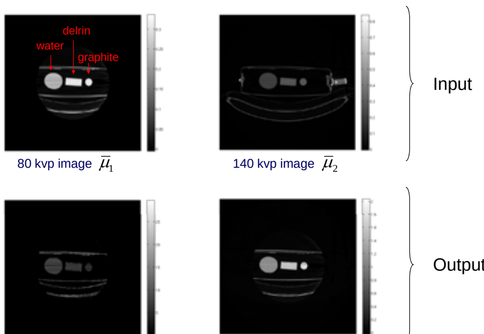
- We scanned some materials provided by LLNL/DHS with Siemens SOMATOM Definition dual-source CT.
- Each source was set to a different spectrum:
  Source A - 140 kvp
  Source B - 80 kvp
- The scanner software reconstructed images of the effective attenuation for both spectra. We chose two images that correspond to the same cross section and applied the method to them.



DHS phantom

Scanner geometry

Experiment Results



80 kvp image $\bar{\mu}_1$

140 kvp image $\bar{\mu}_2$

Effective atomic number $\hat{Z}_{eff}$

Density g/cm³ $\hat{\rho}$

Numerical results - $\hat{Z}_{eff}$

	True value	Estimation mean	Estimation std. dev.
Water	7.42	7.114	1.001
Delrin	6.95	6.206	0.909
Graphite	6	4.795	1.464

Numerical results - $\hat{\rho}$

	True value	Estimation mean	Estimation std. dev.
Water	0.998	1.114	0.069
Delrin	1.41-1.43	1.535	0.116
Graphite	2.09–2.23	1.653	0.264

Conclusions and Future Work

- We implemented a dual-energy image-based method for estimation of Z_{eff} and density on real CT data.
- The method gives reasonable results for low-atomic-number materials.
- The problems with the method:
  - In general, image-domain methods are less accurate than projection-domain methods, since they are based on conventional image reconstruction which ignores the polychromatic nature of the source.
  - The function F(Z) is monotonic only for low atomic numbers (Z<30). Therefore, the method won't work for high-atomic-number materials.
- Future work will include extending the method for high atomic numbers by adding more discriminating features. We will also work on the development of new projection-domain methods.

Acknowledgements:

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References:

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[2] R. F. Eilbert and K. D. Krug, "Aspects of image recognition in vivid technologies' dual-energy x-ray system for explosives detection,"SPIE 1824, 127–143 (1993)

[3] M.J. Berger, J.H. Hubbell, S.M. Seltzer, J. Chang, J.S. Coursey, R. Sukumar, and D.S Zucker, "XCOM: Photon Cross Section Database," National Institute of Standards and Technology, http://physics.nist.gov/xcom.