Coded Aperture X-Ray Fluorescence for Cargo Inspection

David Castañón, Clem Karl and Zach Sun

Boston University
Department of Electrical and Computer Engineering

This material is based upon work supported by the U.S. Department of Homeland Security, Science and Technology Directorate, Office of University Programs, under Grant Award 2013-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.
Conclusions

• Nuclear Resonance Fluorescence provides information on material properties
• Obtaining localization through collimated sensing reduces counts and makes acquisition time slow, limiting use to selective areas
• Using a coded aperture can increase SNR and lower acquisition time, but ...
• Much more to analyze – secondary radiation, multispectral excitation, inverse problems, classification, system concepts & cost, ...

http://www.passportsystems.com/

Department of Electrical & Computer Engineering
Nuclear Resonance Fluorescence

- Nucleus absorbs and reemits high-energy photons (> 1MeV)
- Reemission profile vs energy is characteristic of material
- Can obtain information on elemental composition

Imaging with NRF (Passport Systems)

- Use pencil beam scanning coupled with collimation to localize emission
- NRF Imager inspects localized areas of interest
- Collimation reduces signal preventing NRF from being used on a larger scale
Concept: Use Coded Aperture vs Collimation

- Coded mask can increase effective aperture size, photon efficiency
- Improve measured SNR to reduce acquisition time
Higher SNR of Coded Aperture System

- Single energy, 1-D profile – Improved SNR by 1 order of magnitude

Department of Electrical & Computer Engineering
Signal Inversion Approach

\[ \| y - Cx \|^2 + \alpha \| Dx \|^2 \]

• Assume:
  – Emission independent at each energy
  – No photon interaction between emission and detection
  – Coding mask effect is linear, identical for each energy
  – Independent linear inversion problem at each energy
1-D Simulation Geometry

Detector Array
Random Mask
Material Emission Profile

Excitation Beam

Department of Electrical & Computer Engineering
1-D Simulation Recovered Profiles

One Dimensional Phantom with Poisson Model and Gaussian Noise

Data: 1000 units wide
Mask: 100 units
Sensor array: 1000 units, 3.9 unit res.
Distance Mask to Data: 300 units
Distance Sensor to Mask: 300 units
2-D Simulation Geometry

Detector Array

Random Mask

Material Emission Profile

Excitation Beam Scan

Department of Electrical & Computer Engineering
Two-Dimensional Reconstructions

Image: 1000 x 1000
Sensor: 1000
Mask: 100
Mask to Image: 300
Sensor to Mask: 300
Two Dimensional Simulation

Mean Square Error for one Poisson Realization

Image: 1000cm x 1000cm (256 x 256)
Sensor: 1000cm (256 px)
Mask: 100cm
Distance Mask to Left of Image: 300cm
Distance Sensor to Mask: 300cm

Line by Line Reconstruction, MSE = 0.034119

Calibration, MSE = 0.22233

Image: 1000cm x 1000cm (256 x 256)
Sensor: 1000cm (256 px)
Mask: 100cm
Distance Mask to Left of Image: 300cm
Distance Sensor to Mask: 300cm

Department of Electrical & Computer Engineering

12/9/2014
Conclusions

- Nuclear Resonance Fluorescence provides information on material properties
- Obtaining localization through collimated sensing reduces counts and makes acquisition time slow, limiting use to selective areas
- Using a coded aperture can increase SNR and lower acquisition time, but ...
- Much more to analyze – secondary radiation, multispectral excitation, inverse problems, classification, system concepts & cost, ...

http://www.passportsystems.com/