Next-generation Fast-Neutron/X-ray Scanner for Air Cargo Interrogation

Nick Cutmore, John Eberhardt, Yi Liu (CSIRO)
Rhys Preston, James Tickner (Chrysos Corporation Limited)
Zong Chunguang, Li Jianmin, Li Yuanjing (Nuctech Company Limited/Tsinghua University)
Fast neutron and X-ray imaging

• Developed between CSIRO and Nuctech for scanning large cargo
  ➢ Suited to large structures, but scalable to smaller items

• Cargo is highly variable and heterogeneous making it complex to interpret a single X-ray image
  ➢ Combined x-ray and neutron data simplifies the interpretation of complex images involving multiple material types such as mixed inorganic and organic compounds

• Strong constraints on scanning time, footprint and ease-of-use
  ➢ Evolved a compact high speed imaging solution with sophisticated imaging tools for interpretation of complex data
Implications for technology solutions in consolidated cargo inspection

• Need material discrimination capability
  • For a wide range of material types
  • With resolution of a few mm’s

• Use commercial radiation sources
  • Radioisotopes (not preferred)
  • X-ray tubes or X-ray LINACs
  • Neutron generators

• Image analysis:
  • Overlay material information onto high resolution X-ray images for mm resolution
  • Sophisticated and rapid image manipulation tools developed
  • Automated and semi-automated image analysis tools developed
Technology landscape

"Ease-of-use"

Single/dual energy X-ray imaging

Mark I (2005)

Mark 2 (2008)

Mark 3 (2012)

Lab demo (2003)

3D ‘voxel’ methods

"Threat detection"
Prototype to product

- Prototype system evolved over 4 years
- Commercial partner selection - 2 years
- Product development - 3 years
- Complex landscape of products – where do we fit?
- Competitive tension between technology and process driven industry
Our approach

• Collect high resolution neutron and X-ray radiographic images
• X-ray data provides information about density of material in beam
• Neutron/X-ray interaction cross-section ratio provides information about the average composition of the material in the beam
• Vastly more sensitive than dual-energy X-ray approach
Combined X-ray/neutron imaging

Dual-energy X-ray

R value

0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8

Lead, Iron, Aluminum, Glass, Concrete, Teflon, Graphite, TNT, Cotton, Paper, Rice, Heroin, Morphine, Water, Ethanol, Polyethylene
Collecting X-ray and neutron images

X-rays:
- Electron beam
- Bremsstrahlung radiation
- $10^{13}$ X-rays per second
- $10^5$ X-rays/pixel

Neutrons:
- Deuterium-tritium beam
- Fusion reaction
- $3 \times 10^8$ neutrons per sec
- 15 (!) neutrons/pixel
Compact neutron generator

• Electronic generator produces 14 MeV neutrons only when energised

• Medium-output (3×10^8 n/s) [pulsed generator]
  - Low capital and operational cost
  - Digital control
  - “Return to base” maintainence
  - Reduced shielding footprint – easier to deploy
  - Long tube life at 3×10^8 n/s
Improved neutron detectors

Effective and fast imaging required an improved neutron detector

- CSIRO/Nuctech technology development over past decade
- Basic detector element comprises plastic-scintillator, solid-state photodetector, discriminators and counting electronics
- Main drivers were increasing efficiency and reduced cost

<table>
<thead>
<tr>
<th></th>
<th>Mark 2</th>
<th>Mark 3</th>
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<tbody>
<tr>
<td>Detectors</td>
<td>960 detectors</td>
<td>1440 detectors</td>
</tr>
<tr>
<td>Efficiency</td>
<td>10%</td>
<td>30%</td>
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<tr>
<td>Overall</td>
<td>×5 overall gain</td>
<td>×5 overall gain</td>
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X-ray/neutron image processing

- Raw neutron images have significant artefacts:
  - Noise, due to low neutron intensity
  - Cross-talk due to scattering, which reduced contrast
- CSIRO has developed new, non-linear filtering techniques to decrease noise and increase image definition
- Latest generation of filters allow us to increase imaging speeds 5-10 times whilst preserving image quality
Mark 3 scanner footprint

- Incorporates 6 MV X-ray LINAC and 14 MeV neutron source
- Modular lower cost shielding (steel and recycled materials)
- Integration of X-ray and neutron systems in operation and image analysis
- No exclusion zones exterior to scanner footprint
Image example
Image example
Material identification

• ‘unique’ R-value based image analysis relies upon:
  ➢ High-resolution images
  ➢ Good penetration
  ➢ Good image filtering (uniform colour for uniform materials)
  ➢ Image manipulation tools
  ➢ Background-stripping can correct for overlap to reveal true composition

Image shows combination of metal and organic
Operational experience

• Provides additional information that more quickly defines the makeup of complex bulk cargo

• Overlapping of the transmission images is not always adequately resolved for complex cargo

• Further refinements such as additional views providing limited CT would enhance current technology
  - Limited View / Angle CT Reconstruction
  - 3D reconstruction of limited view and/or limited angle CT data, reduce current CT scanning time and dosage
Industrial Process Imaging?

Neutron/X-ray imaging, developed over more than 10 years, is potentially applicable to industrial applications and provides advantages over X-ray imaging alone

- Material recognition allows recognition and mapping of multicomponent (organic/inorganic) systems at high resolutions (mm’s)

- High rate imaging is compatible with the imaging of rapidly changing systems

- Developments in neutron source optimisation, detectors, shielding and image analysis equally apply in industrial applications

- Developed concepts are scalable and could be deployed in a much smaller footprint suited to specific industrial applications
Thank you

CSIRO Mineral Resources
Dr Nick Cutmore
Research Director

t +61 2 9710 6704
e nick.cutmore@csiro.au
w www.csiro.au