Detection of Landmines using Radiation Based Techniques

Geant4 User’s Workshop, SLAC 2002 02 21

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Overview

- Canadian Landmine R&D Programme
- Detection of Explosives
- Current Radiation Based Techniques
- Imaging
- Use of Geant4
Defence R&D Canada

- Agency within Dept of National Defence (DND)
- Provides and sponsors a broad spectrum of Defence R&D for the Canadian Forces (CF) and DND
DRES

• Principal physical resource of DRES is its location; it is situated on the Suffield "Range" - an area of 2,690 km²

• Experimental Proving Ground (EPG) occupies 1/5 of the range - 431 km²
Technical Solutions to the Mine Problem

Solution

Detection
Neutralization
Protection
Information
Canadian Mine Detection Program

• Countermine
  – Exclusively within DRDC of DND
  – DRES: planning, implementation
  – Aimed at Canadian Forces

• Humanitarian Demining
  – Return land to civilian use
  – DRES: Leverage experience
  – Canadian Centre for Mine Action Technologies
<table>
<thead>
<tr>
<th>De-mining</th>
<th>Countermine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety most important</td>
<td>Speed most important</td>
</tr>
<tr>
<td>Cannot miss any mines</td>
<td>Can miss some</td>
</tr>
<tr>
<td>Must detect AP reliably</td>
<td>Not always necessary</td>
</tr>
<tr>
<td>Uneducated operators</td>
<td>Educated operators</td>
</tr>
<tr>
<td>Not under fire</td>
<td>Can be under fire</td>
</tr>
<tr>
<td>Can choose time</td>
<td>Must go when told</td>
</tr>
<tr>
<td>Can precondition ground</td>
<td>Usually not possible</td>
</tr>
<tr>
<td>Info from combatants</td>
<td>Often not available</td>
</tr>
</tbody>
</table>

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What is the problem?

- Anti-Tank Landmine
  - Designed to destroy heavy armored vehicles
  - E.g. Plastic TMA1 with 5.4 kg of explosives
What is the problem?

• Anti-Personnel Mine
  – Designed to injure or kill
  – Quite often very little metal
  – Can last many years in even extreme environments

• E.g. PMA-3
  – All plastic except for an Aluminum cap in fuse
  – 35 g explosive content
Mine Detectors Available Now

- Metal Detectors
- Prodders
- Human Vision
- All are limited
  - Slow
  - Tedious
  - Dangerous
- Lots of R&D activity, but not much has changed
Why Are Mines Hard To Detect?

- Records are often poor or nonexistent
- Not easy to get close to mines
- They are designed to kill or maim
- Buried mines blend quickly into background
- Surface-laid mines often very hard to see
- Mine properties often are similar to soil

- Many techniques are studied
- We will consider direct detection of the explosives
Methods of Explosive Detection

• Vapour Detection
  – Trace Explosive Detection (TED)

• Bulk Detection
  – Thermal Neutron Activation (TNA)
    • Proto-type, Production & Next Generation
      – Fast Neutron Analysis
      – Nuclear Quadrupole Resonance

• Imaging
  – X-ray, Neutron Albedo
Thermal Neutron Activation

- TNA detects explosive by properties of constituents
  - High concentration of N
  - Does not ID explosive
- Can confirm presence of all surface laid or shallow AT mines in few seconds to 1 minute
- AT up to 20 cm deep and large AP mines in < 5 minutes
Concept of TNA Operation

Neutrons are thermalized and then captured in the Nitrogen of the Explosive, which then emits ‘Characteristic’ Gamma-rays.
Typical Output Spectra

![Graph showing typical output spectra with normalized counts on the y-axis and gamma-ray energy (MeV) on the x-axis. The graph compares different materials and their background.]

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TNA

- Laboratory prototype
  - Not ruggedized
- Works well in extreme conditions
- TNA prototype built by:
  - DRES, DREO, BTI, SAIC Canada
Imaging

• Medical and NDT images employ a 2-sided geometry, i.e. Transmission

• Mine detection limited to single sided access

• Not yet explosive detection, but some techniques moving in that direction

• Radiation based: Neutron, X-ray
Imaging Simulation: Geant4 and ROOT

- Needed robust platform for low energy simulations
- Previous experience with Geant3/PAW
  - Many detector scenarios give opportunity for code sharing
  - Work in an object oriented framework
- Helps to keep up with developments driven by HEP community

△ Simulation suite developed using Geant4 with ROOT used for data archival and analysis

♭ Opportunity to contribute to code verification in Low Energy regime
X-ray Backscatter Imaging

• Exploit Z dependent differences in Compton/Photoelectric cross-sections

• $Z^\text{mine}_\text{eff} \sim 8$ and $Z^\text{soil}_\text{eff} \sim 14$

• Energies 30-60 keV ideal for discriminating low Z materials from heavier elements
  – However, require higher energies for soil penetration

• Design emphasis is on handheld so weak x-ray source preferred

• Simple albedo techniques have not been successful
  – Focus on imaging

• Early R&D stage
  • Modeling study, constructing lab
X-ray Backscatter Imaging

• Cylindrical detector with a coaxial collimated source scanned over surface
• Collimate single scatter photons into radially segmented detector elements
• Integrate over each radial strip to reconstruct voxels at various depths for each scan position
X-ray Backscatter Imaging

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Coded Aperture Imaging

• Technique used in Astronomical, and recently Medical, Imaging

• The recorded picture is
  \[ P = ( O \ast A ) + N \]
  where \( \ast \) is a convolution

• If exists \( G \) such that \( A \ast G \) is a delta function then we can recover \( O \) through post-processing
  \[ O \approx P \ast G = O + N \ast G \]

• Techniques to determine \( G \) made the technique viable

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Coded Aperture Imaging

- Mathematical Deconvolution
- Can use Mask and Anti-Mask apertures to remove imaging artifacts
Coded Aperture Imaging

29 pixel MURA in a 2X2 mosaic, interrogating a volume

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Coded Aperture Imaging

• Image of point source near edge of FOV at depth 53 mm

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Coded Aperture Imaging

- Image of two planar sources at depth 100 mm
Shielding Application

- Calculate effects of various shielding options
- Used Low Energy packages

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Future Work:
Neutron Moderation Imaging

- Fast neutron source, image returned thermal neutrons
- Handheld, weak source
- Potential for AP mines, FAR, moisture a problem
- N moderation has been tried previously, but not imaging
Neutron Moderation Imaging

- Feasibility study (1999) showed that mines can be imaged and proposed a conceptual design
- Follow-on work to build a proof of concept handheld instrument
  - BTI building instrument - complete by 03/02