Imaging for Security Inspection
Ed Morton

www.rapiscansystems.com
Overview

Low Energy Detectors
• Checkpoint X-Ray
• Occupied Vehicle
• High Speed Computed Tomography

High Energy Detectors
• Standard Speed
• High Speed

Reverse Geometry Imaging
• 2D Imaging
• 3D Imaging
Basic Physics
X-Ray Generation

At low energies, X-ray production is almost isotropic.

At high energies, X-ray production is much more forward directed.
X-Ray Spectra – Low Energy
X-Ray Spectra – High Energy

Area of interest for NII

Forward Photon Yield

Energy (MeV)
Material Attenuation

![Material Attenuation Graph]

- Linear Attenuation Coefficient (cm⁻¹)
- Photon Energy (MeV)

- High Energy
- Low Energy
Low energy X-Ray imaging systems
Performance measured in terms of:
- Spatial resolution
- Steel penetration
- Material discrimination
...
Dual Energy Imaging

Incident X-Rays

Low Energy Detector (LE)

Optional Filter

High Energy Detector (HE)
Dual Energy Imaging

HE - LE

HE + LE

Nylon
Aluminium
Steel
Scintillation Based Detectors

0.8 – 2.5mm pitch

Charge integrating ADC (20 bit)

Serial readout at 40MHz

Maximum frame rate 500 Hz
HMEs and Benign Materials in $\rho$-Zeff Space
Effect of Clutter in Bags
Example Images

Automatic Identification
- Explosives
- Narcotics
- LAGs
Semiconductor Based Detectors

CdTe detector array

0.8mm pixel pitch

Dual view with horizontal and vertical beams

Detectors manufactured by MultiX Detection (64 energy bins)

Alternative detectors manufactured by Kromek (5 energy bins)

160kV X-ray generators

~ 5 Mcps/mm2
Example Images

CsI

CdTe
## Scintillator or Semiconductor?

<table>
<thead>
<tr>
<th>Scintillator</th>
<th>Semiconductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost effective</td>
<td>Expensive</td>
</tr>
<tr>
<td>Image lag -&gt; blurred images</td>
<td>Sharp images</td>
</tr>
<tr>
<td>Good detection efficiency</td>
<td>Good detection efficiency</td>
</tr>
<tr>
<td>Large installed base</td>
<td>No field reliability data</td>
</tr>
<tr>
<td>Algorithm performance:</td>
<td>Algorithm performance:</td>
</tr>
<tr>
<td>Approved</td>
<td>Approved, lower Pfa</td>
</tr>
</tbody>
</table>
Occupied Vehicle System Geometry

200kV X-ray source

Tube current dependent on vehicle speed

Data acquisition rate dependent on vehicle speed

2.5mm to 5.6mm detector pitch in linear array

CdWO4 scintillators with low capacitance (20 – 50 pF) diode
Data Acquisition System Architecture

- **Diode Array Board (DAB)**
- **Concentrator Card**
- **Network Switch**

More concentrator cards as needed

- **100Base-T Ethernet**
- **1000Base-T Ethernet**

TCP/IP Ethernet to Control PC

- **Array PC**
Scintillation Based Detectors

20-bit charge integrating ADC on detector boards

Data propagated to DAQ via dedicated serial link

DAQ supports 16 detector boards, outputs 100Base-T Ethernet (UDP format).

Use cascaded Sync to create arbitrary array length

In-system programming of all programmable components

Helps to manage single event upsets caused by radiation interactions
Example Image

200kV X-ray Source

Drive through speed 10 km/h typical

Spatial resolution 4 mm

Typical driver dose < 0.25 uSv. Equivalent to approximately 3 minutes flight time at normal cruising altitude.
Real Time Tomography System Geometry

Conventional CT

Ring of X-ray sensors

RTT

Conveyor Belt

Ring of X-ray sources
Real Time Tomography System Geometry

Multi-focus X-ray tube surrounds baggage conveyor belt.
Electronic switching provides illusion of motion without actual physical movement
Scintillation Based Detectors

16-bit charge integrating ADCs

8 x 16 pixel array format

100-200us signal integration time

160kV X-ray source

LYSO scintillator

Liquid cooled for high system stability

Format data into 1.2Gbps data transmission protocol: HD video 720p
Example Images
High Energy X-Ray Imaging Systems
System Geometry

X-Ray Pulses

Operator Workstation
Dual Energy Imaging

Detector

Linac

6MV 4MV

6MV 4MV Dual Energy

HE - LE

HE + LE

HE - LE

Dual Energy

HE - LE

Energy (MeV)

ONE COMPANY - TOTAL SECURITY
Dual Energy Imaging

Image of a Dual Energy Imaging system with a chart showing signal counts and a legend indicating orange = plastic, green = aluminium, blue = steel.
Scintillation Based Detectors

CdWO4: 5 x 5 x 30 mm sensitive detector element

Arrays of 8 x 1 elements per module, 16 x 1 elements per board. Typically 70+ modules per system = 1100 detector channels

Charge integrating ADC with 20-bit resolution

Same serial readout and data acquisition system as discussed previously

Typical 400 Hz maximum pulse rate (limited by Linac magnetron)
Material Separation Capability
Material Separation Capability
High Speed Imaging

Fan Beam

Cone Beam

LE HE LE HE

LE HE LE HE

LE

HE

LE

HE
Scintillation Based Detectors
Eagle® R60HS Full Scan
Eagle® R60HS Image

Container Full of Household Goods
Reverse Geometry Imaging
X-Ray Compton Backscatter Geometry
Scintillation Based Detectors

1000mm x 300mm x 20mm plastic scintillator

MCA based detector electronics synchronised to collimator position
Scintillation Based Detectors

Monte Carlo model (Geant4) of Compton X-ray scattering into detector panels

Use weighting factors to minimise impact of natural background which will otherwise reduce SNR
Gun and plastic explosive attached to underside of chassis.

Gun and hand grenade placed in spare-wheel compartment underneath High-density plastic sheet for contrast.

Rapiscan Reflexion Product line is not available for sale or use in certain countries. Please check with your Sales Manager as to eligibility for sale.
Rapiscan RXM / RXV Imaging

Rapiscan Reflexion Product line is not available for sale or use in certain countries. Please check with your Sales Manager as to eligibility for sale.
**3D Time-of-Flight Backscatter Geometry**

STFC Daresbury VELA Source

4.7MeV, 100pC bunch charge, 4 ps pulse width

3” diameter CeBr3 detector (Scionix)
Scintillation Based Detectors

Digital pulse shape processing to deal with pulse pileup.

4GS/s sample rate (digital oscilloscope) with 7ns measured rise time

![Graph showing pulse shapes and estimated pulse.](image)
Feasibility Study Results

Single scatter object at two different locations

Lowest energy photons rejected to reduce scatter background

Simultaneous scattering from three separate (nylon) test objects

Photons of all energies included
Next Steps

Array of 50mm x 50mm x 50mm plastic scintillator detectors with fast PMT (ET 9821KB)

2GB/s digitisers with simultaneous sampling on all channels

Expect 300ps time resolution (equivalent to 10cm spatial resolution)

Develop reconstruction algorithms for 3D imaging of large objects

Next data collection planned at Daresbury Lab VELA facility autumn 2014.

Consortium partners:
UCL, STFC, Liverpool, Rapiscan
Imaging for Security Inspection