Driving digital conversion for weld and corrosion inspection: Advances in GE's Digital Detector Array (DDA), Computed Radiography (CR) Technology and X-Ray generator technology

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Imagination at work.
X-ray Imaging Chain with DDAs

- X-ray source
- Transmitted X-Ray Photons
- Object (Feature size and contrast)
- X-ray Photons
- Detector
- Digital Data
- DDA Calibration
- Digital Display

Detector is only a subset of the complete chain

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How does a DDA generate the image?

Millions of components put together to design a DDA

Electron-hole generation
X-ray absorption
Light emission
Light absorption
Electron-hole generation
Conversion to digital signal

Transmitted X-Ray Photons

Scintillator
Pixel Array
Read Out Electronics
Digital Data

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## Industrial vs. Medical X-ray Applications

<table>
<thead>
<tr>
<th><strong>Industrial X-ray</strong></th>
<th><strong>Medical: General X-ray</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High</strong> Dose required</td>
<td><strong>Low</strong> Dose required</td>
</tr>
<tr>
<td>Up to 800kV</td>
<td>Up to 140kV</td>
</tr>
<tr>
<td>High spatial resolution:</td>
<td>Lower spatial resolution:</td>
</tr>
<tr>
<td><em>Object details up to 50μm need to be visible (10 lp/mm)</em></td>
<td><em>Object details up to 200μm need to be visible (2.5 lp/mm)</em></td>
</tr>
<tr>
<td>In-room &amp; On-site:</td>
<td>In-room only:</td>
</tr>
<tr>
<td><em>From Polar circle to Desert</em></td>
<td><em>Room temperature (20 °C)</em></td>
</tr>
<tr>
<td><em>Frost, Heath, Dust &amp; Moist</em></td>
<td><em>Clean &amp; Dry</em></td>
</tr>
<tr>
<td><strong>High X-ray scatter Conditions!</strong></td>
<td><strong>Low X-ray scatter Conditions!</strong></td>
</tr>
</tbody>
</table>

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Progress in DDA Technology for Industrial use

- Film to Digital
- Finer Resolution
- Large area
- Battery operated
- Portable
- Stability
- Increased temperature range
- Faster acquisition
- Extreme pressure conditions
- Standards for DDA

Film to Digital

Large area

Battery operated

Faster acquisition

Increased temperature range

Extreme pressure conditions

Standards for DDA

Stability

Portable

Film to Digital

Finer Resolution

Large area

Battery operated

Faster acquisition

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Extreme pressure conditions

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Film to Digital

Finer Resolution

Large area

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Faster acquisition

Increased temperature range

Extreme pressure conditions

Standards for DDA

Stability

Portable
IQL score = exposure conditions + detector specifications

\[ \mu_{\text{eff}} = \frac{\mu}{1+k} \]

Object & Scatter
- Object material,
- Radiation energy
- Scatter ratio: \( k = \frac{S}{P} \)
- Filtering

\textit{SNR (Conversion efficiency & Noise)}
- Exposure time,
- SDD: Source Detector Distance
- Tube load - Isotope Activity
- X-ray absorption & system gain detector

\textbf{Spatial Resolution} \( SR_b (EN14784-1) \)
- MTF detector
- Magnification
- SDD
- focal spot size source
Life beyond the Nyquist - *Can we see details smaller than the pixel pitch?*

200µm pixel size!

**Test sample**
BAM 5: 8 mm steel

**C1 film:**
- Wire Ø
- EN 462-1
- W13 200µm
- W14 160µm
- W15 130µm
- W16 100µm
- W17 80µm
- W18 63µm
- W19 50µm

**DDA (magnification = 1):**
- W19 = 50µm contrast resolution

High SNR required
Can we measure details smaller than the pixel pitch?

Nyquist limit: spatial frequency corresponding to the pixel pitch

- Aliasing = Image distortion at Sub-pixel resolution
- Size & contrast can not be determined

<table>
<thead>
<tr>
<th>Features desired for Industrial Applications</th>
<th>Field Applications with Isotopes</th>
<th>Computed Tomography</th>
<th>Static DDA applications with x-ray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Frame rate</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Higher Exposure Time</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Varying sizes</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓</td>
</tr>
<tr>
<td>Resolution requirements</td>
<td>✓ ✓</td>
<td>✓ ✓</td>
<td>✓</td>
</tr>
<tr>
<td>Battery operated</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wireless</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced Hysteresis</td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>High Efficiency</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Good Dynamic Range</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

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# GE’s Industrial DDAs

<table>
<thead>
<tr>
<th></th>
<th>Static Detectors (production)</th>
<th>Portable Detectors (field application)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>DXR250</td>
<td>DXR250RT</td>
</tr>
<tr>
<td></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>SCINTILATOR</strong></td>
<td>CsI</td>
<td>CsI</td>
</tr>
<tr>
<td><strong>PIXEL PITCH (µ)</strong></td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td><strong>INTERFACE</strong></td>
<td>Fiber Optic</td>
<td>Fiber Optic</td>
</tr>
<tr>
<td><strong>WIFI</strong></td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>ACTIVE AREA (Inch)</strong></td>
<td>16x16</td>
<td>8x8</td>
</tr>
<tr>
<td></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>ACTIVE AREA (mm)</strong></td>
<td>410x410</td>
<td>205x205</td>
</tr>
<tr>
<td><strong>TEMP CONTROLL</strong></td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>TYPICAL APPLICATION</strong></td>
<td>Automotive, Aero</td>
<td>Welds O&amp;G, Aero, pipe, pressure vessel</td>
</tr>
</tbody>
</table>

Note: Portable DDA´s are NOT intended for high throughput, high energy, repeatable applications!

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Subsea Digital Detector Array

DDAs designed to survive the pressure at 10,000 ft below the sea-level
X-ray Imaging Chain with CR

X-ray source

Object (Feature size and contrast)

Imaging Plate

X-ray Photons

Digital Display

Workstation for scanning
How does an IP and CR scanner generate an image?

- Protective topcoat
- Phosphor layer
- Adhesion / Antistatic / Opt. Filter
- Phosphor grains
- Reflective/Black

Diagram of the process:
- Rotating mirror / Galvo
- Photomultiplier
- Laser
- Light collection
- Powder imaging plate
- Image plate transport
- Digitization
- A/D

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## GE’s CR Scanners

<table>
<thead>
<tr>
<th>Feature</th>
<th>CRxVision</th>
<th>CRx25P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Tabletop</td>
<td>Portable</td>
</tr>
<tr>
<td><strong>Bit depth</strong></td>
<td>16bit SQRT / Lin</td>
<td>14 bit</td>
</tr>
<tr>
<td><strong>Scan resolution</strong></td>
<td>35 , 70</td>
<td>50,100</td>
</tr>
<tr>
<td><strong>Software</strong></td>
<td>NDT designed</td>
<td>Medical spinoff</td>
</tr>
<tr>
<td><strong>IP plates</strong></td>
<td>Scratch protected</td>
<td>Scratch protected</td>
</tr>
<tr>
<td><strong>IP Types</strong></td>
<td>IPC2 - IPS - IPU</td>
<td>IPC2 - IPS - IPU</td>
</tr>
<tr>
<td><strong>Multiplate scanning</strong></td>
<td>yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Cassettes</strong></td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td><strong>Automatic handling</strong></td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td><strong>Data integrity</strong></td>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>50 / 100</td>
<td>27 / 60</td>
</tr>
</tbody>
</table>

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# Tradeoffs

## Computed Radiography
- Flexible image plate
- Low cost to replace imaging plates
- Supports multiple formats
- Need for scan and erase cycle
- Low Efficiency
- High spatial resolution can be achieved with specific image plates (at cost of productivity = exposure time)
- SNR limited by structure noise (FPN)
- Single wire & step hole IQI scores of film only just reached.

## Digital Detector Arrays
- Rigid (mains supply – battery)
- Expensive Detector to replace
- Single format
- Fast time to image (no scanning)
- High Efficiency
- Pixel size limits resolution
- Limited detector format
- High SNR – calibration removes FPN
- Single wire & step hole IQI scores of film exceeded.

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X-Ray tubes optimized for Digital Conversion

• CR based inspection is typically done without using geometric magnification
• To optimize spatial resolution in DDA based inspection geometric magnification can improve results to overcome large pixel size compared to CR
• ERESCO 300 MF4-R comes with 1mm focal spot (3x better) allowing magnification technique

• Additional benefit: High DDA efficiency allows much faster exposure times
Geometric Magnification

System

Three contributions from apparatus:

- Object pixel $V$
- Focal spot size $F$
- Mechanical setup

$U = (M-1)F$
$V = P/M$

The focal spot size is the ultimate limit of resolution.
Applications
Thermal Plant Inspection

- Track to support x-ray tube on the inside of the boiler
- DR panel on the outside of the boiler
- X-ray tube suspended from track with 3-axis of movement
Corrosion
Weld Inspection
Inspecting HV Gas Insulated Switches
Infrastructure

Concrete Inspection
Aero Inspection

Wing Inspections
Automotive - Castings
Military Inspection

Detonator Inspection
Art & Archeological Inspection
Prosthetics
Conclusion

- DDAs and CR are just a component of the complete Imaging chain
- Industrial and Medical X-ray Applications are different and they require unique technology development
- CR and DR have their own pros and cons and should be rightly selected for a given application
- The application space where this technology is used is fast expanding and drives innovation
- To realize a breakthrough for digital conversion, the key is to enable easier workflow and cost benefit of current digital X-ray systems

- The combination of high efficient DDAs, high resolution X-Ray tubes and geometric magnification technique allow to optimize spatial resolution and exposure time