Objective measures of image quality and F792-OE

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Checkpoint x-ray screening

• Image quality standard ASTM F792-08
• Currently under revision and may be split into 3
• One sub-working group is developing an Objectively Evaluated (OE) standard
• General trend toward objectively-evaluated image quality standards
Measuring x-ray image quality

Thin organic detection

Spatial resolution

Penetration
Objective standards

• Create a common language of image quality
• Easy comparison of specifications
• Objective standards are evaluated by an algorithm, rather than a human
• Recent trend towards objective standards
  – CT image quality standard (N42.45-2011)
  – Portable x-ray systems for bomb squads (ANSI N42.45-2013)
  – Checkpoint standard? (proposed ASTM F792-OE)

XRS-4

• 370 KVP
• Penetrates 1.5" Steel
• Weighs 22 Pounds with battery
• DeWalt® 18V Battery pack
• One hour DeWalt® Battery Charger
Objective vs subjective image quality

Subjective test (i.e. judged by a person)
Objective vs subjective image quality

Subjective test (i.e. judged by a person)
Objective vs subjective image quality

Subjective test (i.e. judged by a person)

Objective test (i.e. judged by an algorithm)

ASTM F792

20 AWG visible under 9 mm steel (ASTM F792-OE 2015)

3mm steel

6mm

9mm

ASTM F792-OE algorithm

Image Data

ROI Selection

Statistical significance test

Radon transform

Results
CT screening of checked luggage

- Image quality standard: ANSI N42.45
- Objectively evaluated image quality metrics
- Has proved extremely useful for TSA/TSL and manufacturers
ASTM F792-OE prototype
# Proposed F792-OE metrics

<table>
<thead>
<tr>
<th>Test name</th>
<th>What is meant to be measured</th>
<th>Object on test pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test 1:</strong> Steel Penetration</td>
<td>thickest step that can be discerned from adjacent steps</td>
<td>stainless steel step wedge</td>
</tr>
<tr>
<td><strong>Test 2:</strong> Organic Contrast Sensitivity</td>
<td>contrast between thin organic objects</td>
<td>polyoxymethylene (POM), <em>e.g.</em> Delrin™ step</td>
</tr>
<tr>
<td><strong>Test 3:</strong> Resolution</td>
<td>spatial resolution in the two lateral dimensions</td>
<td>lead foil</td>
</tr>
<tr>
<td><strong>Test 4:</strong> Dynamic Range</td>
<td>how much useful information the system is capable of storing in a pixel</td>
<td>stainless steel step wedge</td>
</tr>
<tr>
<td><strong>Test 5:</strong> Noise</td>
<td>quantifies the frequency-dependent noise</td>
<td>with no test object present</td>
</tr>
<tr>
<td><strong>Test 6:</strong> Useful Penetration</td>
<td>wire visibility through different thicknesses of steel</td>
<td>wires of different diameters behind steel step wedge</td>
</tr>
</tbody>
</table>
Proposed F792-OE metrics

Useful penetration

Steel penetration

Noise

Spatial resolution

Dynamic range

Organic detection
Spatial resolution

Extremely important aspect of image quality

Definition: the ability of a system to resolve, as separate, closely spaced small objects.

**NOT** the smallest object that can be seen

**NOT** wholly determined by number of pixels or pixel size
Spatial resolution in F792-OE

- Measured using a widely-used method called the slanted-edge MTF method
- Result in line-pairs per millimeter
Dynamic Range

- Widely used concept in signal processing
- Dynamic range = \( \frac{\text{Largest signal}}{\text{Smallest increment}} \)

Smallest usable increment = Standard deviation here
Largest signal = Pixel value here
Organic detection

Boundary Signal to Noise Ratio (BSNR)

Computed using multiple images in different orientations

\[ S_i = 1 - \frac{\text{thin step}_i}{\text{thick step}_i} \]

\[ BSNR = \frac{\bar{S}}{\sigma_S} \]
Steel Penetration

- Uses a steel step wedge
- Measures BSNR at every boundary
- Boundary = visible if, BSNR > 5
- What is the thickest step with both boundaries visible?
Useful penetration

- Ability of a system to image wires under blocking material
- Concept exists in human-judged version of F792

- Objective evaluation = a challenge
$R(\rho, \theta) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) \delta(x \cos \theta + y \sin \theta - \rho) \, dx \, dy$

The Radon Transform
Useful penetration

ASTM F792-OE algorithm

20 AWG visible under 9 mm steel (ASTM F792-OE 2015)
# ASTM F792-OE results

- Suite of image quality metrics
- Performance monitoring
- Comparison of systems

<table>
<thead>
<tr>
<th>Image Quality Metric</th>
<th>Vendor A</th>
<th>Vendor B</th>
<th>Vendor C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1: Steel penetration</td>
<td>24 mm</td>
<td>15 mm</td>
<td>18 mm</td>
</tr>
<tr>
<td>Test 2: Organic Contrast</td>
<td>22.9</td>
<td>4.9</td>
<td>2.8</td>
</tr>
<tr>
<td>Sensitivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 3: Spatial Resolution</td>
<td>x-axis: 0.56 lp/mm&lt;br&gt;y-axis: 0.76 lp/mm</td>
<td>x-axis: 0.41 lp/mm&lt;br&gt;y-axis: 0.53 lp/mm</td>
<td>x-axis: 0.48 lp/mm&lt;br&gt;y-axis: 0.54 lp/mm</td>
</tr>
<tr>
<td>Test 4: Dynamic Range</td>
<td>229</td>
<td>72</td>
<td>204</td>
</tr>
<tr>
<td>Test 5: Noise</td>
<td>x-axis: 468²&lt;br&gt;y-axis: 492²</td>
<td>x-axis: 474²&lt;br&gt;y-axis: 363²</td>
<td>x-axis: 151²&lt;br&gt;y-axis: 178²</td>
</tr>
<tr>
<td>Test 6: Useful penetration</td>
<td>20 AWG: 9 mm&lt;br&gt;24 AWG: 6 mm&lt;br&gt;30 AWG: 6 mm</td>
<td>20 AWG: 6 mm&lt;br&gt;24 AWG: 3 mm&lt;br&gt;30 AWG: 0 mm</td>
<td>20 AWG: 3 mm&lt;br&gt;24 AWG: 0 mm&lt;br&gt;30 AWG: -</td>
</tr>
</tbody>
</table>
Conclusions

• There is a trend toward objectively evaluated image quality metrics
• Standard objective methods for measuring image quality make results more reliable and useful
• An objectively evaluated image quality standard has been developed by the ASTM F792-OE sub-working group