Image Quality of Flat Detector Systems

Martin Spahn, Ph.D.

Pittsburgh, July 2004
Agenda

- Technical principles (FD)
- Performance characteristics (FD)
- Image processing
- Image quality control
- Applications in real-time imaging
Flat detector technology is based on CsI and an active pixel matrix of amorphous silicon

Source: Trixell
The high absorption of CsI and the needle structure are necessary for a high quantum efficiency (DQE).

Pixel length typically: 150 µm

Source: Trixell
The individual pixel element is optimized for high photon detection efficiency

Source: dpiX, Trixell
The photodiode of the active pixel matrix translates light into electrical charge

1. preparation

2. exposure

3. after exposure

4. measurement

$\Delta Q$

light quanta

$Q_0$

$Q_0 - \Delta Q$

$Q_0 - \Delta Q$

$+\Delta Q$: el. Signal

Siemens medical
Solutions that help
Agenda

- Technical principles (FD)
- Performance characteristics (FD)
- Image processing
- Image quality control
- Applications in real-time imaging
The Pixium 4600 is a flat detector optimized for radiographic applications

Image of the Pixium 4600 and key parameters

- Scintillator: CsI (600 μm)
- Active area: 43 x 43 cm²
- Size of matrix: 3k x 3k
- Pixel size: 143 μm (Nyquist frequency: 3.5 lp/mm)
- Analog to digital converter: 14 bit
- Readout time: 1.2 s
- No cooling

Source: AX, Trixell
Flat detectors have a large dynamic range

Dynamic range: Comparison of dynamic range of Pixium 4600 and screen film system


The large dynamic range allows a wide range of doses (speeds 200 - 800) and reduces the need for retakes
Flat detectors exhibit high MTF values

MTF: Comparison of MTF measurements of different X-ray detectors

The built-in low pass filter of CsI-based flat detectors help to reduce aliasing effects and the back-folding of noise from beyond the Nyquist frequency limit
Flat detectors reach DQE values well above screen film or storage phosphor systems

DQE: Comparision of DQE measurements of different X-ray detectors


Superior DQE of flat detectors based on CsI/a-Si provides dose reduction potential w.r.t. conventional techniques
Agenda

• Technical principles (FD)
• Performance characteristics (FD)
• Image processing
• Image quality control
• Applications in real-time imaging
Image processing is automatically pre-selected with the choice of the organ program

Image processing for general radiography

- Offset and gain corrections (flat fielding)
- Look-up-tables
- Frequency filter methods (edge enhancement, harmonization, advanced methods)
- Automatic shutter recognition
- Automatic window and level
- Rotation and flip
- Automatic calculation of exposure index (EXI)

The processed image is displayed on the monitor within a few seconds.
Example 1: Flat fielding reduces fixed pattern noise

In addition, variations from the x-ray field due to geometry are compensated.
Example 2: Various Look-up-tables are available for optimized image processing

The FD systems allow to reprocess images with different parameter settings
Example 3: Filter techniques allow to enhance the sharpness or reduce the noise within images.
Example 4: Advanced image processing methods apply a variety of intelligent filter operations (1/3)

- **Signal adaptive spatial filtering**
  - Amplify signals in regions of low contrast
  - Reduce signals in regions of high contrast

- **Image decomposition w.r.t. structure size**
  - Decompose the image into \( n \) layers of different structures size
  - Perform a weighted reconstruction

- **Direction sensitive noise reduction**
  - The direction of images structures is detected and noise reduction done accordingly

Advanced image processing
Example 4: Advanced image processing methods apply a variety of intelligent filter operations (2/3)
Example 4: Advanced image processing methods apply a variety of intelligent filter operations (3/3)
Example 5: Automatic windowing via detection of the collimators and the directly exposed areas

Step 1: image after applying the look-up-table

Step 2: detection of collimator area

Step 3: detection of directly exposed area

Step 4: calculation of center and width

Step 5: image after windowing and cropping
Agenda

- Technical principles (FD)
- Performance characteristics (FD)
- Image processing
- Image quality control
- Applications in real-time imaging
System setup includes sensitivity, image receptor dose adjustments and acceptance tests

Main steps to ensure system setup and quality control

- Adjusted at a well defined and reproducible beam quality (70 kVp, precision filter of 2.1 mm Cu)
- True dose adjustment, i.e. S400 corresponds to 2.5 μGy image receptor dose
- kV response set to constant detector output signal for full kVp range (kV-independent conditions for image processing)
- User interface provides a “sensitivity class” (e.g. S400) which compares easily to former screen-film systems

- Flat fielding calibration on regular basis
- Flat field test
- Dynamic range test (Cu step wedge)
- Spatial resolution test
- Low contrast resolution test
- Exposure index (EXI)

Reviewed on following slides
The visual resolution limit is tested at different dose levels

Limiting resolution test using a lead bar pattern

The limiting resolution does not depend on dose – as expected
The low contrast resolution is tested using a detail contrast phantom at different dose levels

Low contrast resolution test using the CDRAD test phantom

Reference dose

4x reference dose

Significant visibility difference – as expected
The calculation of the exposure index (EXI) helps to track the consistency of system settings

Concept of exposure index

- **What does the EXI provide?**
  - A linear relationship to the image receptor dose
  - A dose indicator depending on the specific organ

- **How does EXI work?**
  - The mean value within one or more ROIs within the image area is calculated

- **Which conditions influence EXI?**
  - The center mean value depends on the organ
  - Geometry, collimation, beam quality (kVp, filtration) influence the EXI

- **Application of the EXI**
  - A twofold EXI value means a twofold receptor dose (comparable conditions)
  - The EXI is a valuable parameter checked in quality assurance e.g. periodic constancy testing
There are 2 alternatives to determine the EXI

Concept of exposure index calculation

Fully integrated system provides positions of active AEC elements:

Determine mean value on pre-processed 14-bit data
AXIOM Aristos FX is a fully integrated radiography system using motorized positioning of the detector.

**Flat Detector for Radiography**

- Area: 43 x 43 cm²
- Pixel size: 143 x 143 µm²
- Matrix size: 3k x 3k
- Analog to digital conversion: 14 bit

**AXIOM Aristos FX**

- Automatic positioning via organ program
- New applications:
  - Lateral and oblique exposures
  - Trauma applications
  - Imaging of immobile patients

Organ programs automatically provide sensitivity class and AEC positions for EXI calculation.
To provide a flexible entry into the digital world a portable detector is used for the AXIOM Multix M

<table>
<thead>
<tr>
<th>Portable Detector for Radiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area:</td>
</tr>
<tr>
<td>Pixel size:</td>
</tr>
<tr>
<td>Nyquist frequency:</td>
</tr>
<tr>
<td>Analog to digital conversion:</td>
</tr>
</tbody>
</table>

EXI is calculated automatically from cropped sub-image
The calculation of an exposure index (EXI) provides a simple way to check consistencies

Examples of exposure index calculation

**Example 1: Thorax p.a.**
- S400 @ 125 kV, 0.8 mAs
- Dose area product: 3.8 μGym²
- EXI: 147

**Example 2: Thorax lat.**
- S400 @ 125 kV, 1.9 mAs
- Dose area product: 10.2 μGym²
- EXI: 314

The EXI is a dose indicator but not a substitute for the dose area product.
Agenda

• Technical principles (FD)
• Performance characteristics (FD)
• Image processing
• Image quality control
  • Applications in real-time imaging
AXIOM Artis dTA systems with large flat detectors were introduced end of 2003

AXIOM Artis dTA: Overview and 30x40 Flat Detector

**Flat Detector for Angiography**

- **Area:** 30 x 40 cm²
- **Pixel size:** 154 x 154 µm²
- **Frame rates:**
  - No binning: 7.5 fps
  - Binning 2x2 pixels: 30 fps
- **Dose ranges:** 10 nGy - 3.5 µGy
- **Analog to digital conversion:** 14 bit

Source: AX PLM-CW
First results of 3D imaging with a large flat detector system

Large flat detector for general angiography: 3D reconstruction of kidney
First studies looking at low contrast resolution of 3-D data sets are very encouraging

Large flat detector: 3D reconstruction of a hand

Source: AX PLM-CW

1) Left: 3D image; Right: Cross section with nicely visible muscles and fat tissue
Magnetic navigation is a new application area where X-ray systems have to operate in magnetic fields

Magnetic navigation in cardiac angiography: Principles

Areas of interest:
- Magnetically guided catheter and guide wire for navigation
- Fixation of ferromagnetic embolic at target sites

This application can only be performed with flat detectors but not with I.I.s

Source: AX PLM-I
With magnetic navigation the catheter can be navigated freely by adjusting external magnets

Magnetic navigation in cardiac angiography: Steering of catheter

Source: AX PLM-I
Our vision: flat detectors will finally be introduced in all X-ray systems

Flat detectors: strategic role
Summary

- Flat detectors, specifically designed for a given application, provide the basis for high image quality (dynamic range, DQE, MTF)
- Digital image processing techniques greatly help to enhance the diagnostic content of the image
- To ensure reliable and constant image quality, the system has to be set up properly (automatic exposure control, kV-dependence) and constancy tests need to be applied (spatial resolution, contrast resolution, exposure index)
- Flat detectors allow to probe into new diagnostic and interventional fields which were not accessible so far