Digital X-ray Imaging

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Outline

- Photon or X-ray Interactions
- Conventional X-ray imaging—Film/Screen
- Digital Imaging
  - CR
  - DR
  - Image processing
- PACS
Photon Interactions (x-rays, γ-rays)

- Coherent scattering (at low energies)
- Photoelectric absorption*
- Compton scattering*
- Pair production (at very high energies)
- Photo-disintegration (at very high energies)
Photon Interactions

Photoelectric Absorption

- Photon transfers all of its energy to an inner shell electron, which is ejected from the atom.
- Likelihood very sensitive to atomic number
  - bone stops x-rays better than tissue
- Likelihood decreases rapidly with energy
  - dominant at low energies
Photoelectric Absorption

Figure 2.6. Photoelectric Absorption. A. Photoelectron production. B. Characteristic x-ray production.
Photon Interactions

Compton Scattering

- Part of energy given to orbital electron and remainder of energy in a scattered photon
- Likelihood not dependent on atomic number
- Likelihood falls off slowly with energy
  - dominant at the higher energies
- Dominant interaction in soft tissue at Dx energies
  - but not of the iodine contrast media
- Source of exposure to personnel in fluoroscopy
Compton Scatter

Figure 2.7. Compton scattering.
How an X-ray Image is formed
Conventional screen/film detector

1. Acquisition, Display, Archiving

Transmitted x-rays through patient

Film processing:
light to optical density

Gray Scale encoded on film

Film

Intensifying Screens

x-rays → light
Digital X-ray Detector

1. Acquisition

Transmitted x-rays through patient

Charge collection device

X-ray converter

x-rays → electrons

2. Display

Digital Pixel Matrix

Digital to Analog Conversion

Digital processing

3. Archiving

Analog to Digital Conversion

Digital to Analog Conversion

Digital Pixel Matrix
Digital Detectors

- Separation of acquisition, display and archive
- Digital acquisition is *not contrast limited*
- Signal to Noise Ratio → “image quality”
- Detector DQE determines the exposure required to achieve a required SNR
Characteristic Curve: response of screen/film and PSP detectors

- Film-screen (400 speed)
- CR plate
- Sensitivity (S)

Exposure, mR
Relative intensity of PSL
Film Optical Density
Correctly exposed
Underexposed
Overexposed
Useless
CR: BaFBr converters

- Standard resolution plates: ~100 µm thickness
- Double sided readout: 150 µm thickness
- \( \text{Gd}_2\text{O}_2\text{S} \) phosphor more efficient at higher energy: higher Z, greater mass thickness

DR: CsI converters

- Structured phosphor minimizes light spread
- Thicker phosphor layer (300 – 500 µm)
- High absorption and good conversion efficiency
X-ray absorption Efficiency: CsI, BaFBr, Gd$_2$O$_2$S

- CsI: 175 mg/cm$^2$
- Gd$_2$O$_2$S: 120 mg/cm$^2$
- BaFBr: 100 mg/cm$^2$
Absorption Efficiency

- Only one part of the story
- Spatial resolution tradeoff?
- Conversion efficiency
- Other noise sources (electronic, pattern)
- Detective Quantum Efficiency (DQE)

**Thick Screen:**
- Good Absorption
- Poor Resolution

**Thin Screen:**
- Poor Absorption
- Good Resolution

**Structured Phosphor:**
- Good Absorption
- Good Resolution
Data conversion

Exposure into digital number

Grayscale transformation
Input to output digital number

Histogram

1. Find the signal
2. Scale to range
3. Create film look-alike
Pre-processed
no window/level

Contrast enhanced
Computed Radiography Response
Shading, Flat-Field correction

- Reduce structured noise
- Eliminate variable background
- Increase DQE(f)
  - Detective Quantum Efficiency

![Graph showing DQE(f) for Flatfield and Raw data](image)
Image quality depends on more than quantum mottle!

Screen-Film

Flat-field pre-processing

125 kVp 2 mAs

aSi/CsI Flat-Panel

MDACC: Chris Shaw, et al

Low contrast resolution
Detective Quantum Efficiency, $DQE(f)$

\[ DQE(f) = a \times MTF(f)^2 / (NPS(f) \times q) \]

Spatial Frequency (cycles/mm)
Digital X-ray Systems

**Computed Radiography**
- Portables
- ICU / ER / Trauma
- Mobile X-Ray

**Digital Diagnost**
- High Volume Bucky
- Spine, Shoulder, Knee, Abdomen, Pelvis, Hip, Ribs
Electronic Imaging Schematic

x-ray Patient → Image Receptor → A - D Converter → Computer

Network

Monitor or Laser Printer ← Image Display ← D - A Converter
IMAGE ACQUISITION

- Image is obtained by
  - image intensifier in fluoroscopy
  - Computed Radiography, CR
  - Direct Radiography, DR

- A-D, analog to digital converter
  - Electronic device that transforms continuous x-ray density (analog signal) into a set of discrete gray levels (digital signal)
IMAGE ACQUISITION

- Digital image can be manipulated by the computer using algorithms designed to display the information in the most useful form.

- Image manipulation
  - window & leveling
  - edge enhancement
  - zoom, subtraction
  - last image hold
CR IMAGING PLATES

Imaging Plates and Cassettes

- Same size, shape as conventional film cassettes
- Re-usable
- High Dynamic Range
- Bar Code Label
Imaging Plates

- **BaFBr:Eu & BaF'I:Eu**
  - Europium doped, 85% Br
- Attenuates best between ~35 to ~50 keV
- Below and above this range rare earth has better attenuation
- May use higher kVp for extremities
CR IMAGE ACQUISITION

- Computed radiography using photostimulable phosphor
  - Image plate of barium fluoride bromide
  - X-rays “trap” electrons in crystal structure
  - Red light liberates electrons which emit blue light
  - Blue light from screen is read by PMT
  - Image is digitized
  - Image plate is erased to remove old image
CR IMAGE ACQUISITION

Diagram showing the process of CR image acquisition:
- Laser beam
- Optical scanner
- Photomultiplier tube
- Light guide
- Imaging plate
- Motor
- Analog to digital converter
- Amplifier
Computed Radiographic Imaging
DR FLAT FIELD DETECTOR

- Amorphous silicon
- Need fluorescent material
  - CsI
  - Screen
- No cassettes, called DR
DR Amorphous Silicon

- Cesium Iodide scintillator over amorphous silicon photodiodes
- GE
- Siemens
- Philips
Indirect Conversion

- Scintillator of Cesium Iodide
- Amorphous silicon photodiodes convert light to electric charge
- Charge stored as pixel capacitance
- Readout through TFT
The Cesium Iodide channels the x-rays providing high contrast images.
Canon DR

- Gd$_2$O$_2$S:Tb
- Image access time 2-3 seconds
- Refreshment cycle 6 seconds
- 4.2 GB (300 images)
- 17 x 17
- 160 micron/pixel
Canon DR
a-Si Sensor Plate
Photograph of a Pixel

data line

gate line

bias line

a-Si TFT

a-Si MIS-type photoelectric converter

Pixel size: 160 micron x 160 micron
Fill Factor: 0.48
Construction of Panel

* Detector Size: 43cm x 43cm (16.9” x 16.9”)

* Image Matrix: 2,941 x 3,021

* Pixel Size: 143 µm

* Highly Integrated SMD Technology
Digital Diagnost
Charge Coupled Device Technology (CCD)

Courtesy of Swissray
CCD

Swissray ddR Multi-System

Courtesy of Swissray
DIRECT CONVERSION

- Amorphous selenium
- Flat panel detector
- Converts x-ray to electric charge
- Charge collected at electrode
DIRECT CONVERSION

- The charge collects at storage capacitor for each pixel
- Thin film transistor (TFT) switch or gate for each pixel
- Signal is read out pixel column by pixel column through TFT

Magnified view of a portion of the TFT matrix. Arrow points to the center portion of a single detector element (139x139 microns). The detector element is shown in comparison to the width of a human hair (80 microns).
The technology uses an amorphous selenium-coated thin-film-transistor (TFT) array to capture and convert X-ray energy directly into digital signals; the need for film as a means of capturing an image is eliminated. Under a bias voltage applied across the detector structure, incident X-rays directly generate electron-hole pairs in the selenium layer. These charges are collected by individual storage capacitors associated with each detector element for readout by customized electronics within the array.
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Picture Archival and Communication System - PACS

- Computer Based
Many forms of archiving or storage exist

- film
- magnetic tape
- magneto-optical disk (analog)
- laser optical disk (digital)
NETWORKING

- PACS - Picture Archiving and Communications System
- DICOM - Digital Images and Communications in Medicine
STREAMLINING WORKFLOW

PACS is about ...

- Managing Patient Folders
- Streamlining Workflow
- Film Reduction

Handling patient folders electronically is similar to handling the film based folders
Thank You