"Photon Counting Medical X-ray Imaging from Mammography to CT"

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Sponsors for the Project

The Erling-Persson Family Foundation

CT Gantry

PHILIPS
Clinical Applications

Chest Radiography
Bone Densiometry
Computed Tomography
Mammography
Angiography
Mammography
Digital Subtraction Radiography

Other Applications

Non Destructive
Testing Airport Security

High Resolution X-ray Imaging in the Physics Division at LBNL
Who Counted Photons First?

What was that?

Maybe a photon
To Count Photons – What does it mean?

- Number of X-rays
- Pulse height give the energy for each X-ray
- No electronic noise

Result

Energy

Threshold 1
Threshold 2
Threshold 3
Electronic noise

X-ray photons

1 2 3 Time
Integrating Current: Today’s praxis in X-ray Imaging

Result

- Area of
- Indirect estimate of number of photons
Photon Counting or Integrating –
Two Ways of Eating the Smorgasbord

The normal way (one dish at a time)

Mix everything before you eat and try to guess the ingredients
Example of Clinical use Today: Mammography
Adaptation to mammography

Shorter detectors

Smaller pixels - higher resolution?

Possibility of adjusting the scan speed for differences in breast thickness

Basic approach of using silicon strip detectors wirebonded to ASICs stays the same
Photon Counting Mammography
Spiculated mass
Crystalline Silicon Detector
Scanning slot approach

Advantages:

Scatter rejection (reduced dose to patient)

Possibility to adjust scan speed to tissue transmission

Facilitates calibration

Drawbacks:

Mechanical scanning mechanism needed

Longer image acquisition time (around 10 s)

Higher load of X-ray tube, movements during scan would distort image
DQE at Zero Spatial Frequency

![Graph showing DQE (0) vs. entrance dose (µGy)]

- PHILIPS Micro Dose Photon Counting

Clinical Example: Experience from Breast Check, the Irish Breast Screening Program

- 4 static & 16 mobile screening units
- Equipment:
  - 11 CsI scintillator
  - 10 a-Se
  - 7 Photon counting
Ireland Breast Screening Program
Cancer Detection Rates

Ireland Breast Screening Program
Radiation Dose

Visualization of Iodine Contrast Agent

- 35 mm invasive lobular carcinoma
- Difficult to detect in 2D
- Difficult to detect in tomosynthesis
- Energy subtraction – clear improvement in this case

Courtesy Dr. Felix Diekmann
Differentiation of Cysts from Cancer
On the photo you can tell what is what…
But on the X-ray image, can you tell what is what?
On photon counting spectral you can!

Spectral image of Aluminium

All acrylic removed

Spectral image of acrylic

Aluminum removed
Measuring breast tissue attenuation

Björn Cederström, Erik Fredenberg
Philips, Solna, Sweden
Matthew G. Wallis, Paula Willsher,
Cambridge Breast Unit and NIHR Cambridge Biomed. Research Centre, U.K.
David R. Dance, Kenneth C. Young,
NCCPM, Royal Surrey County Hospital, U.K.

Setup:
– cyst samples in 1-cm cuvettes
– PMMA + Al step wedge

Method:
– Map cyst fluid directly into (PMMA, Al)-space

Measurement of solid tumor attenuation

• Published data on tumor composition/attenuation scarce

• Different experimental condition

• Use same setup as for cyst fluid

• Tailored sample holder
Clinical use in the Future: Computed Tomography
Overview of detector

- Detector element size: $0.4 \times 0.5$ mm$^2$
- Depth segmentation: 16 segments along incident direction
- 8 thresholds for each channel
ASIC – Developed for Silicon Spectral CT

150 Analog Inputs

80 Analog Channels

Block of 20 Analog Channels

80 Analog Channels

Digital part
Detector Materials
## Detector Materials for Spectral Photon Counting

<table>
<thead>
<tr>
<th>Material</th>
<th>Signal (20 keV X-ray)</th>
<th>Fano-factor</th>
<th>Speed (ns)</th>
<th>70% Absorption Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>5500</td>
<td>0.1</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Gas (Krypton)</td>
<td>770</td>
<td>0.2</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>CdTe/CZT</td>
<td>2000</td>
<td>0.1</td>
<td>10</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Compton Scattering versus Photo-effect

Silicon

CdZnTe
Front-end Electronics
-very similar to high energy physics
• Fast
• Small Signals
• Low noise
• Massive parallel processing
• Small channel to channel variation
• Low power
• Temperature stable
• Digital readout not inducing noise
Electronics for Photon Counting

Pre amp → Shaper → Multi-level Comparators and Counters → Memory

Oscilloscope Screen-dump
Problems:
Pile-up and charge sharing
Are we fast enough?

- 120 kVp polychromatic x-ray spectrum
- 33 ns deadtime per x-ray detection
- Linear relation up to 200 Mcps/mm²

![Graph showing X-ray count rate (Mcps/mm²) vs. Input count rate per channel (Mcps).](image)

**Maximum clinical count-rate**

- [0, 160, 320, 480, 640, 800] X-ray count rate (Mcps/mm²)
Measurement of Energy Resolution - Example

\[ f(x; \mu, \sigma, A, B) = \frac{1}{2} \text{erfc}\left(\frac{x - \mu}{\sqrt{2}\sigma}\right)(A(x - \mu) + B) \]
Measurement of Energy Resolution - Example
Normalization
Threshold off-set
Clinical Benefit Example: Bone versus Iodine

Voxels with different materials can appear the same in image

Iodine - Concentration matching Calcium attenuation

Calcium
Wear in Knee Replacements

Image Courtesy of Dr L. Wiedenhielm, Karolinska Hospital, Stockholm Hospital
Silicon CT segmented image
Clinical trial focusing on stroke planned for 2015
Project Background

Patent for the idea granted to David Nygren 1995

During the last 6 months:

A flexible personal computer based data acquisition system has been developed

The 16 channel ASIC has been fabricated and tested to work according to our specifications

Detectors have been manufactured and dark currents have been measured to be in the order of 10 pA as expected

The ASIC has been wirebonded to the detector and signals obtained from radioactive source

Currently everything is ready for mounting in the X-ray cabinet and we will very soon scan our first images.

The project has been supported by the physics division by about $40k/year
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X-rays have color

Thank’s!