I-ImaS

CTI:

Enhancements to the image pre-filtering and image restoration options, and preface to x-ray camera geometry

Athens, 29th – 30th September 2005

Current Progress Overview:

- WP3: issues related to D.8 and D.9 material
- Overview of image pre- and post-filtering
- Enhancements to image restoration options
- Preface to x-ray camera geometry (WP8)
- Implementation & calibration issues
- Aspects relative to “Exploitation & Dissemination”

Additional comments for D.8 & D.9:

- Use of greyscale: sensor-to-pixel values, scale, normalization
- Visualization correction model: regression models
- Dose, mAs, kVp: textural features, feedback, “dose” type, beam hardening
- Pre-filtering: non-destructive noise removal, interleaving, sub-sampling

Comments from CTI:

Report: *“CTI: Additional comments regarding D.8 and D.9 reports”*

I-ImaS website: “`I-ImaS_CTI_D8-D9comments_Sept05.pdf`” / 08-Sept-05

Image acquisition model:

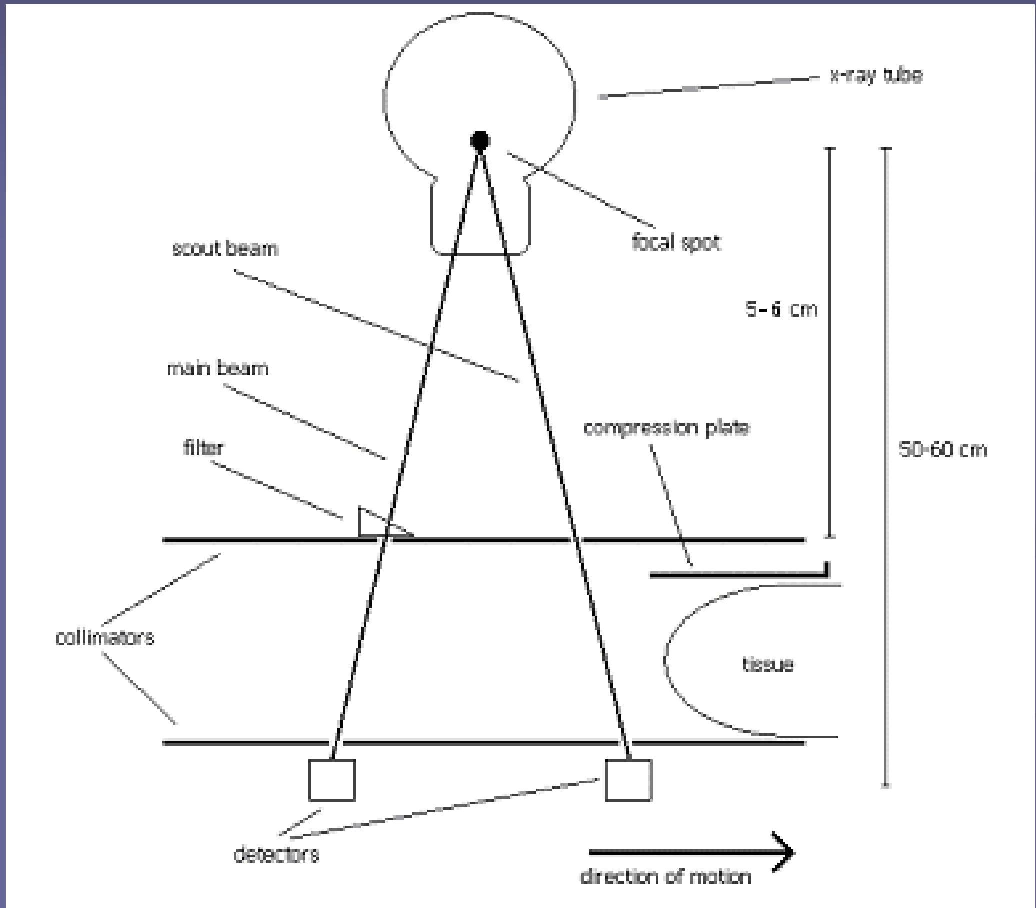


Figure adapted from [30]
A.Galbiati, Feb/05

Image distortions detected at the sensor plane:

1. Disuniformities on sensors, scintillator, etc.
2. Combined noise factors
3. Relative target-sensor movement (line-scanning)
4. “Salt & Pepper” type disuniformities (black/white spots)
5. Non-uniform gain profile (vingetting)
6. Perspective distortions
7. Other geometric/lens distortions (barrel-pincushion)

Goals of study:

- Initial approach (D.9): “black-box” model estimation – complex
- Analytical approach: “white-box” model estimation – modular
- Scope: include some of the “white-box” model within the acquisition/control loop (on-line processing) for better quality on the extracted textural features (input).

Type-1 Distortion: Disuniformites on sensors

- Usually a result of non-uniform scintillator coating
- Also includes “bad pixels”
- A uniform “void” exposure can estimate the complete spatial profile
- Usually the simplest method for flat-field correction

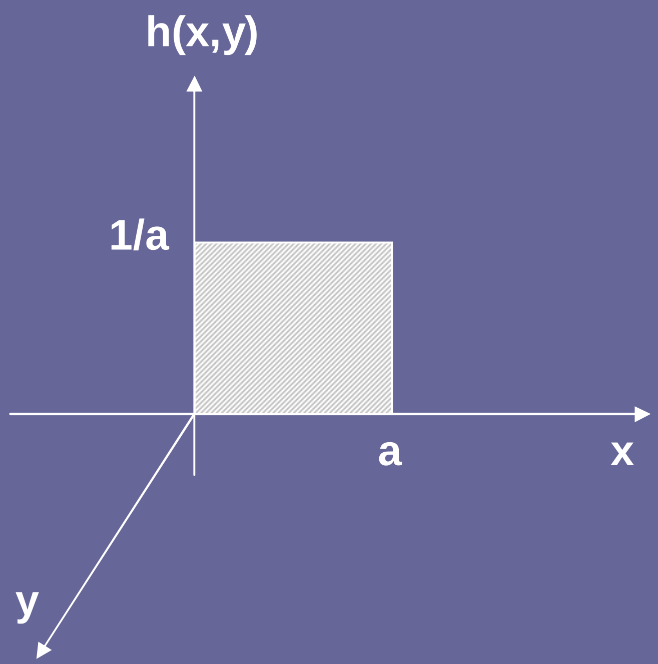
Type-2 Distortion: Overall noise artifacts

- Refers to all image artifacts of stochastic nature
- Includes sensor inefficiencies (thermal/electronic noise)
- Includes beam scattering
- May also refer to quantization if precision is low
- It can be modeled statistically and removed at some degree
- Non-destructive filtering requires accurate noise & acquisition models

$$\eta(x,y)=\sqrt{g(x,y)}\cdot\eta_1(x,y)+\eta_2(x,y)$$

Type-3 Distortion: Relative movement between object and sensor

- Caused by the line-scanning procedure
- Resulting PSF for pixels is wide along the scanning direction
- Creates a "smoothed" version of the ideal image
- Can be corrected via accurate model estimation and filtering



Impulse Response: h(x,y)

$$\frac{1}{a_0}\cdot rect\left(\frac{x}{a_0}-\frac{1}{2}\right)\cdot\delta(y)$$

Frequency Response: H(ξ1,ξ2)

$$\mathrm{sinc}(\alpha_0\xi_1)\cdot e^{-j\pi\xi_1\alpha_0}$$

Wiener filters for image restoration

- More stable and noise-resistant than inverse and pseudo-inverse filters
- Does not require analytical mode for the channel (adaptive on statistics)
- Combines optimal combination of low-pass and high-pass filtering
- “Smoothing” for noise reduction, “Sharpening” for PSF correction
- Can be “trained” with a calibration template (fixed) or adapt to the channel

Analytical form of frequency response of Wiener filter:

$$G(\omega_1,\omega_2)=\frac{H^*(\omega_1,\omega_2)\cdot S_{oo}(\omega_1,\omega_2)}{\left|H(\omega_1,\omega_2)\right|^2\cdot S_{oo}H(\omega_1,\omega_2)+S_{\eta\eta}H(\omega_1,\omega_2)}$$

Typical implementation via correlation statistics (spatially invariant form):

$$r_{od}(x,y)-\sum_{i\in W}\sum_{j\in W}\left[g(i,j)\cdot r_{dd}(x-i,y-j)\right]=0 \quad , \quad \forall(x,y)\in W$$

Note: Size of spatial kernel depends on PSF “smoothing”, typically less than 15x15 pixels

Type-4 Distortion: "Salt & Pepper" disuniformities

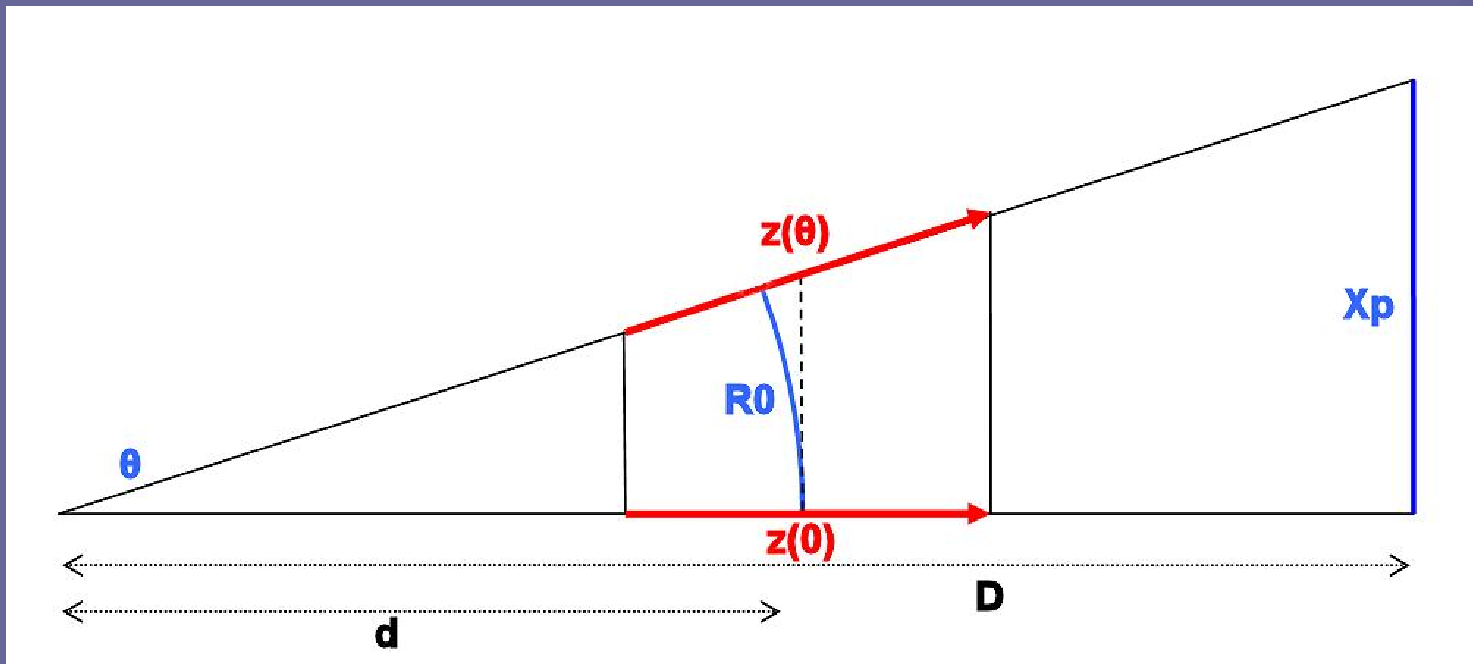
- Appear as extreme bright ("salt") or dark ("pepper") spots on the image
- If consistent, they can be attributed to sensor deficiencies (see Type-1)
- If random, they are pixels saturated with extreme noise values
- Normal noise filtering is incapable of completely restoring these pixels
- Instead, "spot" filters are used for detection & interpolation
- Usually implemented as 2-D Gaussian kernels with threshold "triggering"

$$H_{SP}(g) = \begin{cases} A \quad , \quad g = a \{"pepper"\} \\ B \quad , \quad g = b \{"salt"\} \end{cases}$$

! Caution: Spot detectors must be able to clearly distinguish between "salt & pepper" spots and useful image content, e.g. microcalcifications: For minimum size 0,3 mm at pixel size 32x32 um, the spot detector kernel should be much smaller than 9x9 pixels wide.

Gain Profile Distortions: Vingetting, Perspective, Lenses

- Vingetting: Image fades near the border due to decrease of gain
- Perspective: Additional gain decrease due to disperse of photons over increasing area until they hit the sensor plane.
- Lenses: Cause perspective-like non-linear effects on image morphology, usually referred to as “barrel-pincushion” distortions, NOT an issue in typical x-ray projections



Type-5 Distortion: Vingetting – Non-uniform gain profile

- Commonly referred to as "vingetting" in the final image (fading near border)
- Caused by non-uniform absorption profile and conical projection (see Type-6)
- If object is assumed homogeneous, analytical geometrical model is feasible

$$\theta_{xy} = \arctan\left(\frac{\sqrt{(x-X_0)^2+(y-Y_0)^2}}{D}\right)$$

$$A(T) = A_0 \exp\left(-\left(g\cdot\mu_{glandular} + (1-g)\cdot\mu_{fatty}\right)\cdot T\right) = A_0\cdot e^{-GT}$$

$$\rho_1(\theta) = \frac{A(T_\theta)}{A(T_0)} \xrightarrow{breast=B} \frac{A(B/\cos\theta)}{A(B)} = C\cdot e^{d\,(1-\cos^{-1}\theta)}$$

Note: Correction of the gain profile is also possible by using standard flat-field correction templates (see Type-1), if a realistic object substitute is included during the estimation of the sensor response profile.

Type-6 Distortion: Perspective – Conical projection geometry

- Caused by conical projection from a point source to a flat plane
- More evident when object is placed far from the sensor plane
- More evident when source is placed near the object
- Usually included in the vingetting distortion (see Type-5)
- If the geometry of the system is fixed, analytical geometrical model is feasible

$$\rho_2 = \frac{I_\theta}{I_0} \quad \frac{N/S_\theta}{N/S_0} \quad \frac{S_0}{S_\theta} \quad \frac{R0^2\,\delta\theta^2}{D^2\tan^2\delta\theta} \xrightarrow{\delta\theta\to 0} \frac{R0^2}{D^2}$$

Overall gain correction function
(parameter estimation via calibration)

$$d(x,y) = C_1\left[\frac{R0^2}{D^2}\cdot e^{d\,(1-\cos^{-1}\theta_{xy})}\right] + C_0$$

$$gain(x,y) = {}^{1}\!/_{d(x,y)} \quad , \quad d(X_0,Y_0) = 1$$

Note: Correction of the gain profile is also possible by using standard flat-field correction templates (see Type-1), if an isotropic beam scans throughout the entire sensor plane and a realistic profile is created for the background.

Overview of complete image restoration process:

raw image acquisition | noise reduction | move/PSF correction | feature extraction

sensor-field correction | spot/pixel correction | gain/pixel correction

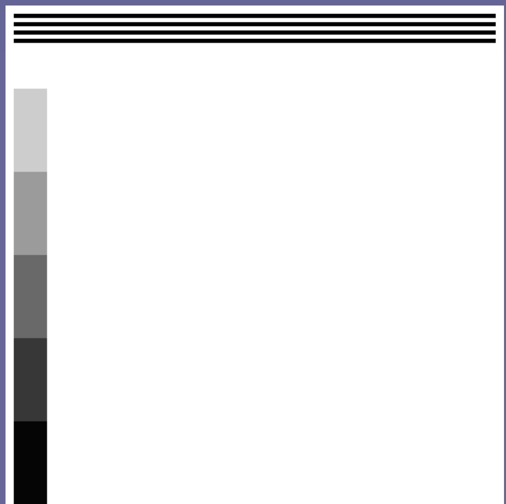
- Different stages embed different levels of complexity and processing time
- Exact ordering and sequence of the stages **IS** important for optimum results
- Ideal case: feature extraction comes after the last restoration stage
- Real case: embed as many stages as possible within the on-line loop

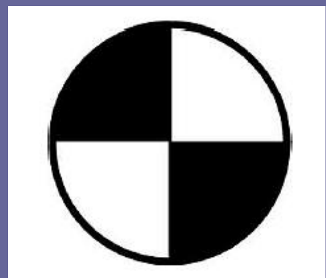
Design & Implementation Plan:

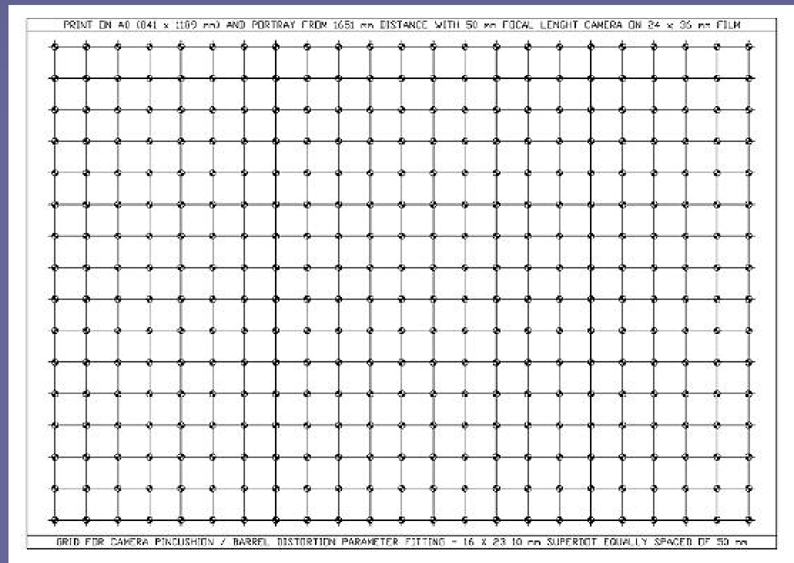
- Split the complete sequence into pre- and post-processing modules
- On-line processing loop includes pre-processing modules, plus feature extraction, plus control logic
- Remaining restoration modules are placed off-line as post-processing

Calibration

- Sensor-field correction: requires full sample "template" of the imaging area
- Wiener filters: combined noise and PSF measurements (assumed invariant)
- Gain correction: analytical geometric model OR full flat-field gain response







Figures (b) and (c) adapted from [31], Paolo Greppi, Aug/03.

What about the wedge filters?

- Probable modification of beam spectrum profile, not just the intensity
- If profile modification is significant, separate calibration sets may be required

Overview of exploitable knowledge (WP3):

ID	Exploitable knowledge	Exploitable products or measures	Sectors of application	Timetable for commercial use	Patents or other IPR protection	Owner & other partners involved
#17	Textural feature extractors for on-chip image quality evaluation on medical X-ray images	Software + model design	X-ray imaging	As soon as protected	Copyright Possible patent for model design?	5 CTI 7 SINTEF 9 UoT
#18	Generalized controller design for the on-line adaptive X-ray exposure control IC	Software + model design	X-ray imaging + Academic	As soon as protected	Copyright Possible patent for model design?	5 CTI 7 SINTEF 9 UoT
#19 **	Generalized filter design for image restoration of raw images from the line-scanning system	Software + model design + calibration	X-ray imaging + Academic	As soon as protected	Copyright Possible patent for model design?	5 CTI

** **Note:** Item #19 will also include results from the x-ray camera design (WP8) for improved restoration

Future Work (CTI):

Next major workpackage involvements in:

1. WP8 – "X-ray camera design and manufacture" (Tasks: 8.2, 8.3), starting in Dec/05.
2. WP9 – "System display system and camera control" (Tasks: 9.2, 9.3), starting in Jan/06.
3. Additional work: consultation on implementing the image processing, on-line control and efficient code for filtering modules.
4. As soon as a prototype of the complete acquisition system is ready, test runs are necessary for the verification, calibration & optimization of all the modules involved in imaging and control.

Suggestive References:

[23] *I-ImaS, Workpackage 3 – Deliverable D.8*, "Translating information signatures to a sequence of well-defined processing functions", Feb.2005

[24] *I-ImaS, Workpackage 3*, "Update on current progress and report for deliverable D.8", CTI presentation for 3rd I-ImaS meeting, London, 12-13 Oct 2004

[25] I-ImaS, Workpackage 3 – *Deliverable D.9*, "Different approaches to providing intelligence to the sensor/imaging system", Mar.2005

[26] I-ImaS Workpackage 3, "Update on current progress and deliverable report D.8", CTI presentation for 4th I-ImaS meeting, Oslo, 14-15 Feb 2005

[27] "D.9 – Considerations from Trieste", WP3 communication, May-Aug 2005.

[28] I-ImaS, Workpackage 6 – *Deliverable D.17*, "Report on trade-offs for possible sensor/ASIC architectures for the chosen application", Apr.2005

[29] I-ImaS, Workpackage 5 – *Deliverable D.14*, "Top-level system designs", Mar.2005

[30] I-ImaS report, "Update Report on I-Imas Intelligent filters for Intensity Modulated Breast Imaging", Arnaldo Galbiati, Feb.2005

[31] "Experimental measurement of the camera intrinsic camera parameters", Paolo Greppi, 27-Aug-03.