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Life and Death of Pixels

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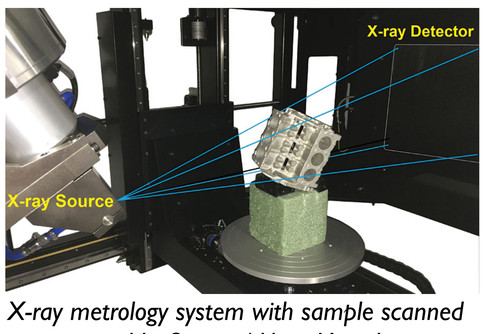
Introduction

X-ray detectors frequently develop dysfunctional pixels and inhomogeneous performance. Questions arise around potential reasons for these spatial patterns.

Parametric models are used to describe spatial inhomogeneity of the (functional) pixel intensities. They can fit linear gradients introduced by the sub panel configurations and elliptic spots created by the X-ray cone.

We move from the notion of a ***dysfunctional pixel*** to the higher level concept of a ***damage event***, i.e. a grid based configuration of dysfunctional pixels. In addition, high density regions of damage are detected using density estimation and are candidates for physical causes of damage. Remaining areas suitable candidates for CSR.

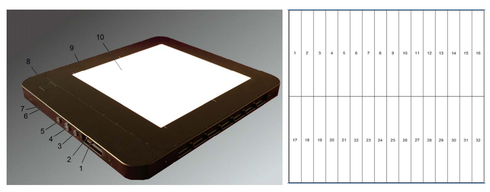
Technology & Data



X-ray metrology system with sample scanned on rotary table. Source: Nikon Metrology

Bad pixel map data set

- Perkin Elmer definition of "underperforming" pixels
- Lists of grid coordinates
- 4 dates before repair, 2 after



Detector: Perkin Elmer flat screen XRD 1621 with 2000x2000 pixels in 2 rows of 18 sub panels each

Raw data set

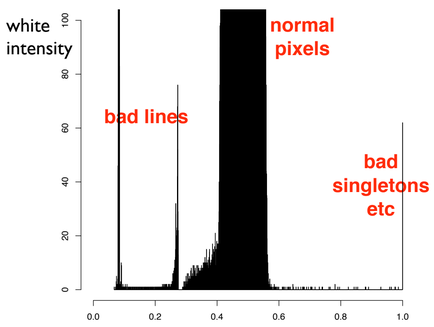
- Acquisitions without sample
- Series of 20 for each channel
- White (85kV, 80microA)
- Grey (85kV, 20microA)
- Black (0kV, 0microA)

Exploratory Data Analysis

Taxonomy for bad pixels by spatial pattern (*)

- Singletons
- Doubles
- Small clusters
- Lines to midline
- High density regions
- Corner damage

Link intensity with type



Questions & Challenges

- Describe spatial distributions of dysfunctional pixels and their properties
- Link their occurrence to physical causes
- Assess data quality after removal of obvious special causes for poor quality
- Understand relationship between dysfunctional pixel type and intensity
- Study spatial variation of the intensity
- Understand the effect of subpanels
- Model uneven distribution of X-ray exposure

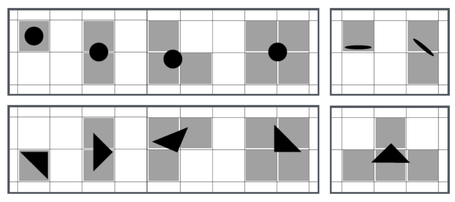
Spatial Modelling and Analysis

Simple model:

Pixel process. Dysfunctional pixels as planar point process X

Criticism:

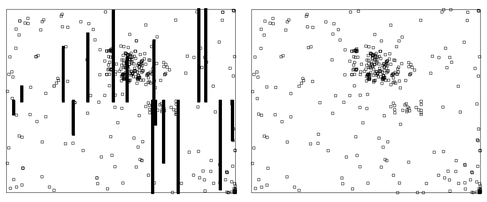
- Hardly ever ***completely spatially at random (CSR)***, because of clustering via nearest neighbour relations as in (*), but need to study CSR beyond obvious hurdles.
- Potential mismatch of physical causes for damage and their manifestation in pixel grid:



Damage covering multiple pixels results in undesirable dependency on shape, position and grid resolution.

Revised model:

Damage event process. Damages under (*) as elementary events of planar point process Y



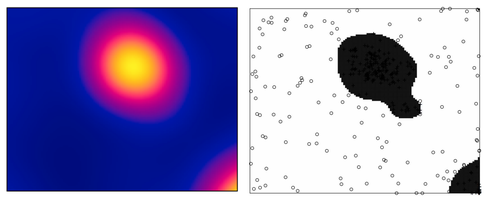
(a) Pixel process (b) Event process (marks not visualised)

Inhomogeneous density:

Kernel based estimation of inhomogeneous density ψ_Y defines threshold

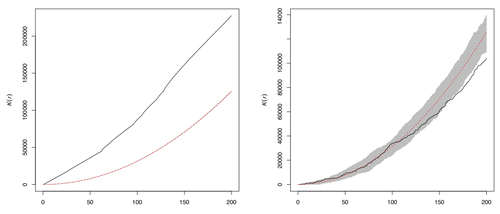
$$\delta = q_u(\psi_Y) + \delta_0 \cdot \mathrm{IQR}(\psi_Y)$$

(q_u upper quartile, δ_0 user defined) for defining area of increased damage. Restricting process has typically homogeneous density.



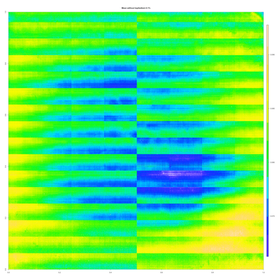
Testing for CSR:

Ripley's K-function, the expected number of extra points in circle, rescaled by density, increases proportional to the area under CSR.

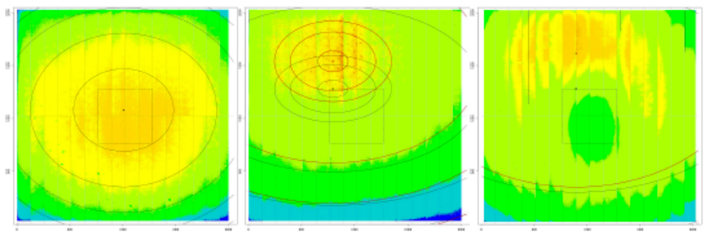


K-function for dysfunctional pixel process (left) and restricted damage event process (right) with corresponding CSR process including confidence bands. Pixel process not CSR, while restricted event process is.

Parametric Spatial Models



Inhomogeneity due to subpanels can typically be fit with linear gradients based models. Circular pattern can be observed in addition to that. Detector are exposed X-rays travelling in a cone extending from the source. We fit parametric models for elliptical spot pattern with optional constraints on model centre being within a 512-pixels-square of detector centre.



RMSE 186 RMSE 501 (226) RMSE 574 (553)

Gaussian spot models with (*black*) and without (*red*) constraints on centre for different response types with RMSE with (without) constraints demonstrating capabilities and limitations of this approach.

Conclusions & Applications

- Higher level point process are superior models for spatial analysis of pixel based damage and link observed damage more directly to physical causes.
- Parametric intensity models improve correction of artefacts such as subpanel and uneven X-ray exposure.
- Methods applicable to detector damage explanation, monitoring, prevention.

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