# Identification of In-Field Sensor Defects in the Context of Image Age Approximation

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# Outline

# Image Age Approximation

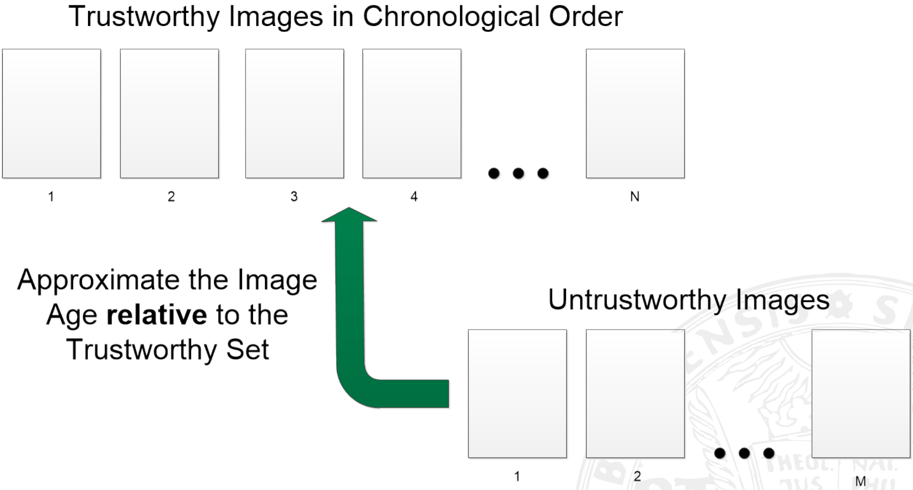


Figure: Overview image age approximation.

# Image Age Approximation

Available age approximation methods based on the presence of in-field sensor defects.

- Fridrich et al. proposed a maximum likelihood approach for image age approximation in [1].
- We regard image age approximation as a multi-class classification problem and proposed to utilize two well-known machine-learning techniques in [2].

The defect locations have to be determined in advance.

$\Rightarrow$ Reliable Methods for defect detection in the context of image age approximation are required!!

# In-Field Sensor Defects

In-field sensor defects are studied in various publications, e.g. [3, 4, 5, 6, 7, 8]. In summary:

- Develop after the manufacturing process and accumulate over time. $\rightarrow$ increases linearly with time.
- Are due to cosmic radiation.
- Are randomly distributed over the sensor area.
- Spread to the neighboring pixels because of preprocessing (e.g., demosaicing).
- Appear as point like, spiky shot noise.
- The trend towards ISO expansion and smaller pixel sizes increases the defect development rate.

# In-Field Sensor Defects

To model a defective pixel, we rely on the definitions stated in [1].
By assuming no noise or other imperfections, a defective pixel can be defined as,

$$f(I) = I + \tau D + c. \tag{1}$$

Figure: In-field sensor defects extracted from captured dark-field images.

# Defect Examples


Figure: In-field sensor defects in a regular scene image.

# Defect Examples

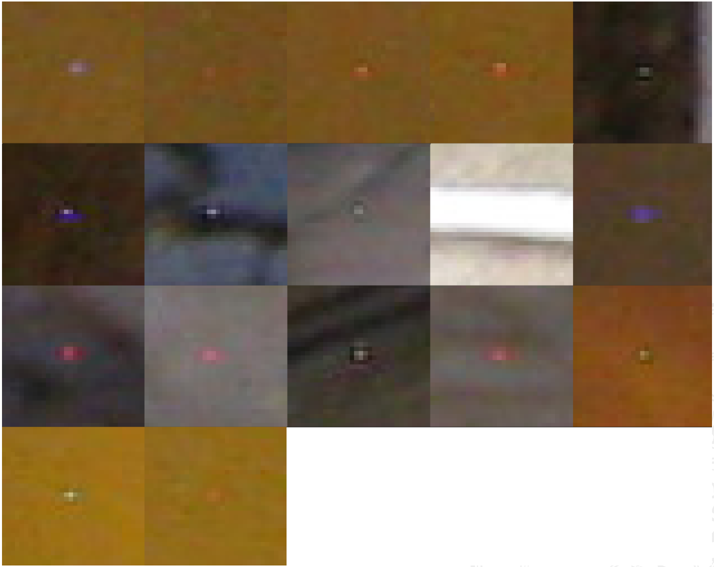

Figure: In-field sensor defects in a regular scene image.

# Defect Detection Methods - Notation

- Let $S$ be the set of chronologically ordered trusted images
- The subset $S_1 \subset S$ contains the first $n$ and $S_2 \subset S$ the last $m$ images
- The sets $R_1$ and $R_2$ contain the corresponding median filter residuals
- Let $\vec{s}_1$ be an $n$ and $\vec{s}_2$ an $m$ dimensional vector containing the values of an arbitrary but fixed pixel over $S_1$ and $S_2$
- The corresponding noise residuals are represented by $\vec{r}$

**Goal:** Only detect defects relevant for image age approximation, i.e. which developed within the time interval of $S$.

# Spatial only Detection

- Fridrich et al. suggest to threshold the median filter residual in [1]
- Since the median filter completely smooths out a peak in a homogeneous area, the method can be considered as 'spatial only' detection

## Spatial only Detection

A pixel is regarded as a defect candidate if the inequality

$$\sigma^2(\vec{r}_2) > t, \qquad (2)$$

$$\text{where} \quad t = \mu + \sigma * w$$

holds. The global threshold $t$ is defined by the average residual variance $\mu$, the residual variance standard deviation $\sigma$ and an adaptive weight $w \in \mathbb{R}^+$. The mean and standard deviation are computed over all pixels.

- Based on the differences in residual values before and after the defect onset

## Spatial Detection with Temporal Information

A pixel is considered defective if,

$$\sigma^2(\vec{r}_1) < \sigma^2(\vec{r}_2) \;\wedge\; ||\vec{r}_2'||_1 > \alpha * |R_2|, \tag{3}$$

$$\text{where} \quad \vec{r}_2'(i) = \begin{cases} \vec{r}_2'(i) = 0, & \text{if } t_l < \vec{r}_2(i) < t_u \\ \vec{r}_2'(i) = 1, & \text{otherwise,} \end{cases}$$

$$\text{and} \quad t_{l,u} = \lceil \text{median}(\vec{r}_1) \rceil \mp w_S * \sigma(\vec{r}_1).$$

The parameter $\alpha$ controls the amount of residual values in $\vec{r}_2$ that have to be outside of $[t_l, t_u]$

# Spatial Detection with Temporal Information

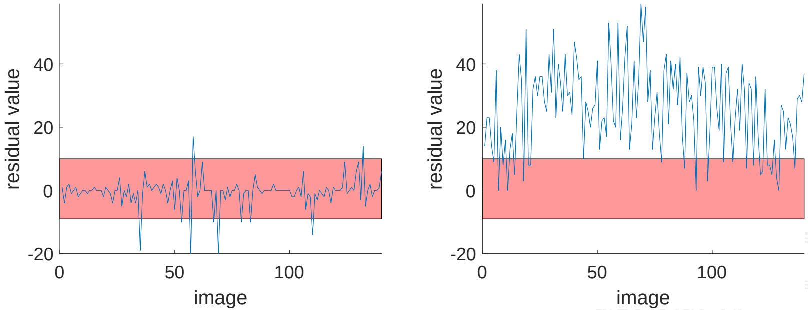


Figure: The left diagram shows the residual values before the defect onset and the residuals after the onset are shown in the right diagram. The interval $[t_l, t_u]$ is represented by the area shaded in red.

# Temporal only Detection

- Based on the influence of the defect on the pixel's dynamic range.

## Temporal Only

A pixel is considered defective if,

$$\sigma^2(\vec{s}_1) > \sigma^2(\vec{s}_2) \;\wedge\; ||\vec{s}_1'||_1 > \alpha * |S_1|, \tag{4}$$

$$\text{where} \quad \vec{s}_1'(i) = \begin{cases} \vec{s}_1'(i) = 1, & \text{if } \vec{s}_1(i) < \hat{c} + w_T \\ \vec{s}_1'(i) = 0, & \text{otherwise} \end{cases}$$

$$\text{and} \quad \hat{c} = \min(\vec{s}_2).$$

The parameter $w_T$ represents the variable offset $\tau D$, and $\hat{c}$ is an estimator of the potential offset $c$.

# Data Sets

- Four available data sets:
  - Nikon E7600, 1768 images ($S_N$)
  - Canon PowerSht A720IS, 4379 images ($S_C$)
  - Pentax K5, 4725 images ($S_{P1}$)
  - Pentax K5II, 1881 images ($S_{P2}$)
- The subsets $S_1$ and $S_2$ contain 140 images each.
- All Nikon and Canon images are JPEG compressed and all Pentax images are PNG compressed 8 bit RGB colour images of regular scenes.

# Scene Samples

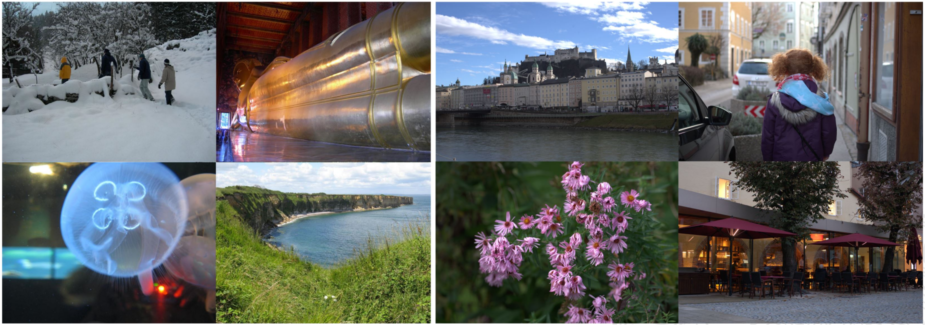

Figure: Random samples of set $S_N$ (top left), $S_C$ (bottom left), $S_{P1}$ (top right) and $S_{P2}$ (bottom right).

# Performance Evaluation

- The f1-score is used to asses the detection methods performance

$$f1 = \frac{2TP}{2TP + FP + FN}. \quad (5)$$

- The ground-truth is extracted out of dark field images

# Experimental Results - Detection Performance

| Method | nikon01 | canon01 | pentax01 | pentax02 |
|---|---|---|---|---|
| spatial only | 0.1247 | 0.3666 | 0.2250 | 0.3262 |
| spatial & temp. | **0.1474** | **0.7531** | **0.4139** | **0.6630** |
| temporal only | 0.0594 | 0.6830 | 0.1882 | 0.1788 |

Table: Average maximum f1-score.

# Experimental Results - Detection Performance

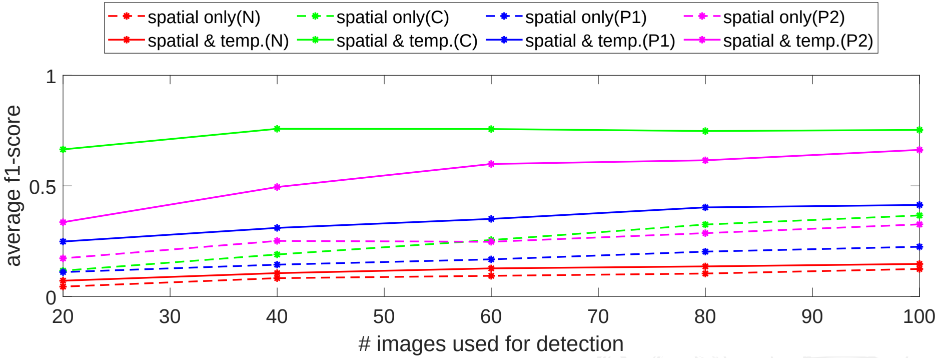


Figure: Shows the maximum average f1-score over the amount of used input-images.

# Experimental Results - Impact on Age Prediction

| Set | Method | KDc | NB KDE | SVM |
|---|---|---|---|---|
| nikon01 | spatial only | 0.8653 | 0.7822 | 0.8949 |
| | spatial & temp. | 0.9041 | 0.7886 | **0.9232** |
| canon01 | spatial only | 0.8299 | 0.8720 | 0.8030 |
| | spatial & temp. | 0.8172 | 0.9139 | **0.9867** |
| pentax01 | spatial only | 0.7671 | 0.9367 | 0.9323 |
| | spatial & temp. | 0.7250 | **0.9435** | 0.9202 |
| pentax02 | spatial only | 0.6876 | 0.8786 | 0.8518 |
| | spatial & temp. | 0.6710 | 0.8718 | **0.9041** |

Table: Average age approximation accuracy between images of $S_1$ and $S_2$.

# Conclusion

- We introduced two novel defect detection methods in the context of image age approximation
- The 'spatial detection with temporal information' outperforms the 'spatial only' approach proposed in [1].
  - In average a 0.0227, 0.3856, 0.1889 and 0.3368 higher f1-score is reached (Nikon, Canon, Pentax K5 and Pentax K5II).
  - In average 5 more defects are found, which increases the accuracy of a subsequent age approximation.
  - Increases the robustness with respect to a lower amount of input images.
- Due to the high scene dependency, the 'temporal only' methods are not very reliable

Thank you for your attention!

# References


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