Inpainting-based Camera Anonymization

S. Mandelli, L. Bondi, S. Lameri, V. Lipari, P. Bestagini, S. Tubaro
Motivations

• When **privacy** related to digital images ownerships is a concern
  • Censorship
  • Photo-reporters protection in hot zones
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- When **privacy** related to digital images ownerships is a concern
  - Censorship
  - Photo-reporters protection in hot zones

- **Remove** every way to back-track to the original photographer
  - Metadata manipulation
  - Sensor fingerprint removal or obfuscation
Problem Formulation

- Camera characterized by a certain Photo-Response-Non-Uniformity signal
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- Image shot with the same camera
Problem Formulation

- Camera characterized by a certain \textit{Photo-Response-Non-Uniformity} signal
- Image shot with the same camera
- \textbf{Noise residual} extracted from the image to perform \textit{cross-correlation} test
Goal

- **Anonymize** the image

- Preserving perceived image quality

- **Reducing cross-correlation**
  so that image source attribution becomes impossible
Basic Idea

- **Substitute** each *pixel* of the image with an *inpainted* version based on its *neighbors*, so to corrupt PRNU traces embedded into it.

![Original image](image1.png) ![Anonymized image](image2.png)
Basic Idea

- **Substitute** each pixel of the image with an **inpainted** version based on its **neighbors**, so to corrupt PRNU traces embedded into it.

![Original image](image1.png) ![Anonymized image](image2.png)

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Basic Idea

- **Substitute** each pixel of the image with an **inpainted** version based on its **neighbors**, so to corrupt PRNU traces embedded into it.
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Proposed Algorithm
Overview

Block Selection → Inpainting → Block Merging

Edge Detection → Denoising

Logical Complement
Proposed Algorithm Overview

1. Block Selection
2. Inpainting
3. Block Merging
4. Edge Detection
5. Logical Complement
6. Denoising

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Proposed Algorithm
Block selection

• Create **several versions** of the image with **missing** pixels

• Holes based on a regular grid
Proposed Algorithm

Block selection

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Proposed Algorithm
Block selection

- Create **several versions** of the image with **missing** pixels
- Holes based on a regular grid
Proposed Algorithm
Block selection

- Create **several versions** of the image with **missing** pixels
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Proposed Algorithm
Holed images inpainting

- **Inpainting** through regularized inversion

\[
\arg_{\tilde{I}} \min \| S\tilde{I} - I \|_F^2 + \mu \| R(\tilde{I}) \|_p^p
\]
Proposed Algorithm
Holed images inpainting

- **Inpainting** through regularized inversion

\[ \arg\min_{\bar{I}} \|S\bar{I} - I\|_F^2 + \mu \|R(\bar{I})\|_p^p \]

- Fitting condition on original pixels

\[ \|S\bar{I} - I\|_F^2 \]
Proposed Algorithm

Holed images inpainting

- **Inpainting** through *regularized inversion*
  \[
  \arg_{\hat{I}} \min \|S\tilde{I} - I\|_F^2 + \mu \|R(\tilde{I})\|_p^p
  \]

  - Fitting condition on original pixels
  - Regularization term to impose smoothness
    - First derivative operator
    - L1 (Total Variation) and L2 norm (Tikhonov)

\[
\|S\tilde{I} - I\|_F^2
\]

\[
\|R(\tilde{I})\|_p^p
\]
Proposed Algorithm
Block merging

• Merge selecting only reconstructed pixels
Proposed Algorithm
Block merging

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Block merging

• Merge selecting **only reconstructed pixels**

• Drawback: **quality loss**
Proposed Algorithm

Edge Reconstruction

- Canny \textit{edge detector} on original image

- Edge \textit{dilation}
Proposed Algorithm

Edge Reconstruction

- Canny edge detector on original image
- Edge dilation

denoised edges
Proposed Algorithm

Edge Reconstruction

- Canny **edge detector** on original image

- Edge **dilation**

- **Paste denoised edges on inpainted image**
  to improve visual quality
Experiments and results

Setup

• Dataset
  • 600 RAW uncompressed images
  • 512 x 512 pixels
  • Dresden Image Dataset

• Wavelet denoising
  • Camera PRNU estimation
  • Image noise residuals

• Performance evaluation in terms of
  • Receiver-Operating-Characteristic
  • Area-Under-Curve vs SNR
  • TPR vs SNR (at fixed FPR)
Experiments and results

ROC

![Graph showing ROC curves for L2 and L1 norms with 3 and 5 pixel holes.](image)

- L2 norm
  - 3 pixel holes
  - 5 pixel holes
- L1 norm
  - 3 pixel holes
  - 5 pixel holes

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Experiments and results

ROC

L2 norm
3 pixel holes

L2 norm
5 pixel holes

L1 norm
3 pixel holes

L1 norm
5 pixel holes
Experiments and results
Comparison with SOTA

![Graph showing AUC and Median PSNR for L2 and L1 norms with different pixel hole sizes.]

- L2 norm
  - 3 pixel holes
  - 5 pixel holes
- L1 norm
  - 3 pixel holes
  - 5 pixel holes

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Experiments and results
Comparison with SOTA

![Graph showing TPR versus Median PSNR for different norms and hole sizes.]

- **L2 norm**: 3 pixel holes
- **L2 norm**: 5 pixel holes
- **L1 norm**: 3 pixel holes
- **L1 norm**: 5 pixel holes
Conclusions

• So far
  • **Simple** anonymization strategy
  • Block-wise inpainting is easily **parallelizable**
Conclusions

• **So far**
  - **Simple** anonymization strategy
  - Block-wise inpainting is easily *parallelizable*

• **The future**
  - Investigate more *sophisticated* solutions
    - Take care of edge reconstruction at inpainting phase
  - Effectiveness on **JPEG** compressed images
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