Using Sensor Pattern Noise for Camera Model Identification

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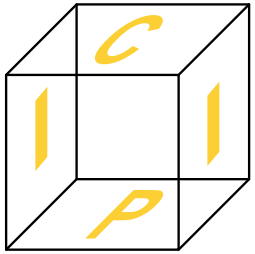

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Image Forensics

Photographs (were) are (will be) modified for different reasons.

Can we trust the content of a digital media?

The goal of image forensics is to

- detect image forgeries, recover processing history
- determine the source of an image
  (scan, computer graphics, digital camera, ...)
- link the image with known device (digital camera)

Applications (silent witness in court):

- child pornography - Was given image taken by this camera?
- movie piracy - What camera was used to tape the movie in cinema?

Digital Camera Fingerprint & PRNU

Sensor fingerprint is unintentionally embedded into every image. Caused by imperfections in manufacturing process

- slightly varying pixel dimensions
- inhomogeneities in silicon.

Properties:

- multiplicative noise (PRNU) unique to every sensor
- high-dimensional, spread-spectrum signal.

Applications:

- reliably identify a *specific* camera
  Detect the presence of the sensor fingerprint in an image.
- image forgeries
  Detect the consistency of the fingerprint in small neighborhood.

[Chen, Fridrich, Goljan, Lukáš. Determining Image Origin and Integrity Using Sensor Noise, IEEE TIFS, 2008]

Goal of Our Work

Sensor fingerprint:

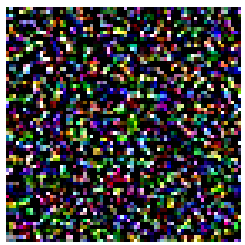
- unique characteristic of a camera

Can we determine camera model (brand) from the given fingerprint?

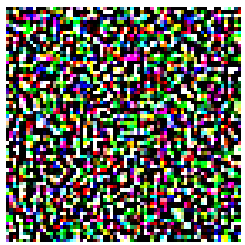
Other properties:

- uncorrelated with other fingerprint from different camera
- different visual structure when estimated from different camera models

Fingerprint estimates:

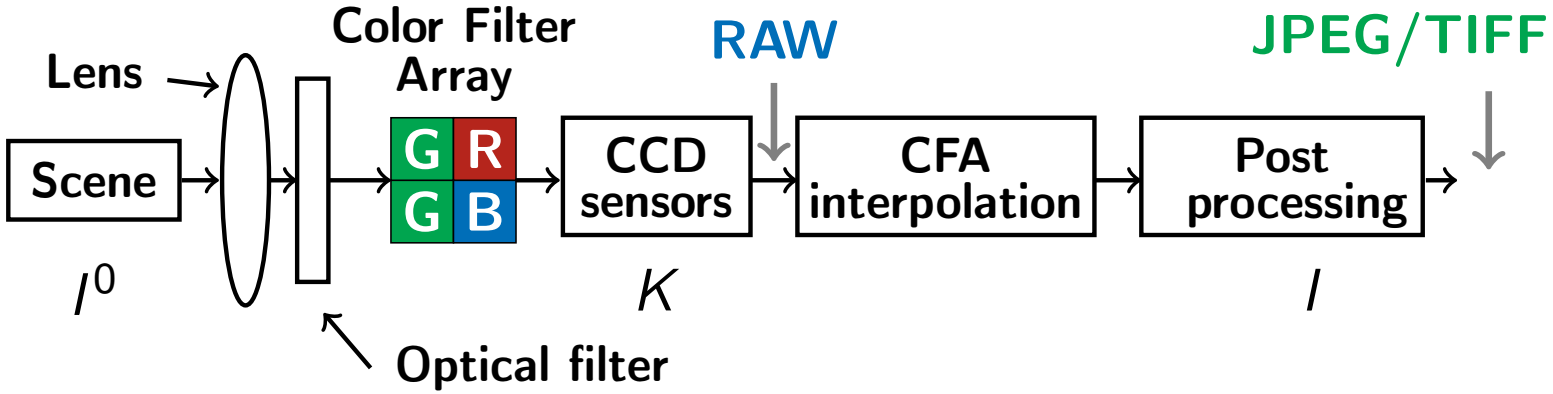


Canon
PS SD-400



Panasonic
DMC-FX01

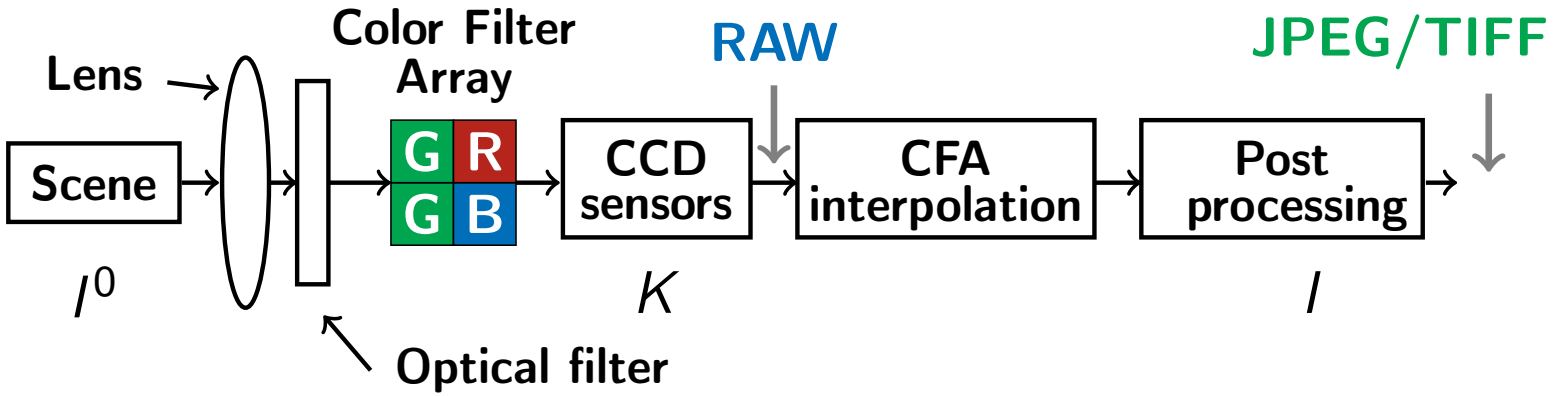
Simplified Camera Model



$$I = I^0 + \gamma I^0 \cdot K + \Theta$$

- I^0... original scene, I ... final image
- K ... Photo Response Non-Uniformity (PRNU)
- γ ... term coming from Gamma correction
- Θ ... other types of noise sources

Camera Fingerprint Estimation



$$I = I^0 + \gamma I^0 \cdot K + \Theta$$

Fingerprint estimation (MLE): **(element-wise operations)**

$$\hat{K} = \frac{\sum_{i=1}^{m} W_i I_i}{\sum_{i=1}^{m} (I_i)^2} \qquad W_i = I_i - Denoise(I_i)$$

$\{I_i\}$ **set of** m **images used for estimation.**

Camera fingerprint estimated from JPEG/TIFF images contain traces of camera processing.

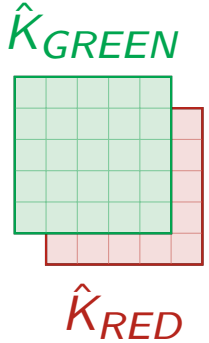
Fingerprint Classification - Feature Description

Statistical moments:

First 3 centralized sample statistical moments were calculated from each color channel of $\hat{K}$.

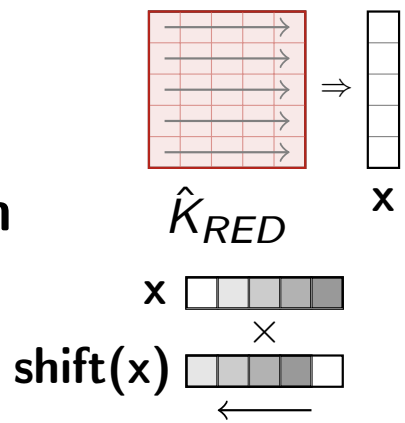
Normalized cross-correlation:

For each color channel pair (C_1, C_2), $C_1, C_2 \in \{R, G, B\}$ and shift $\Delta_1, \Delta_2 \in \{0, \ldots, 3\}$, we calculate the normalized cross-correlation $\rho(\Delta_1, \Delta_2)$, between $C_1(i,j)$ and $C_2(i-\Delta_1, j-\Delta_2)$.

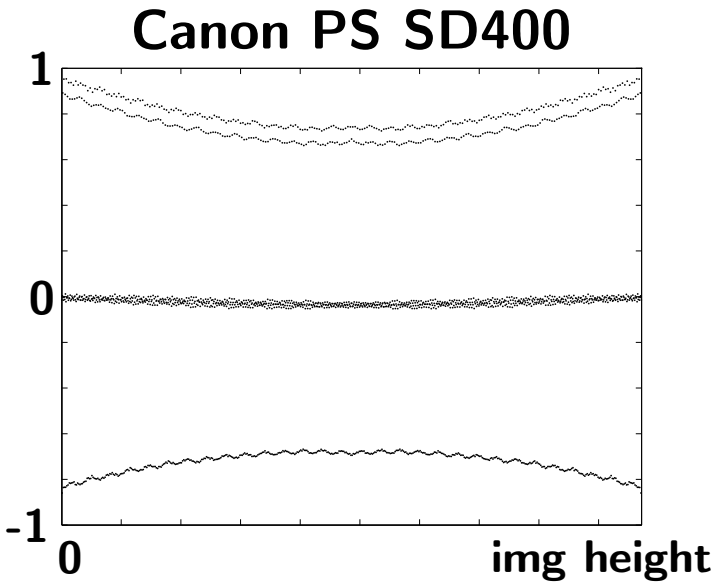


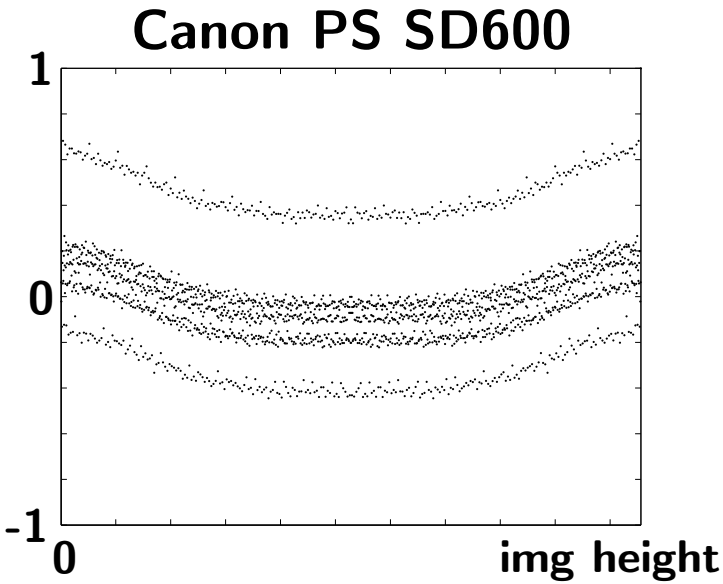
Linear-pattern cross-correlation:

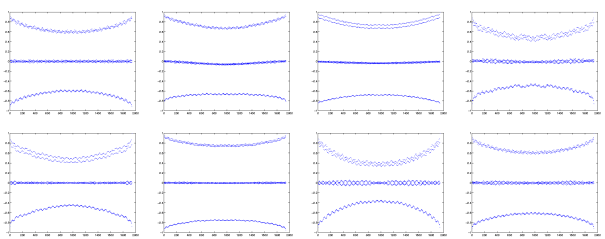
Calculate autocorrelation of the linear-pattern $\mathbf{x} \in \mathbb{R}^{h \times 1}$, where $\mathbf{x}_i$ was obtained as a mean of i-th row of the red color channel.

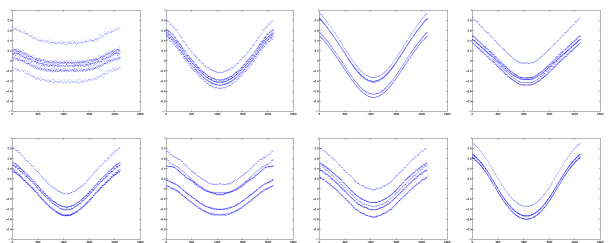


Linear-pattern Cross-correlation









Cyclic normalized cross-correlation of vector $\mathbf{x} \in \mathbb{R}^{h \times 1}$, where x_i was obtained as a mean of i-th row of red color channel of fingerprint $\hat{K}$.

Data Collection

Requirements:

- 45 full-resolution images from each camera to est. $\hat{K}$
- 100 different cameras for each model
- many camera models and brands to perform real test.

Database:

- 17 camera models, 8 brands
- total 4,565 cameras and 205,425 images.

All images were obtained from image sharing portal www.flickr.com.

Training data: 70 cameras for each model

Testing data: 30-580 cameras for each model

45 full-resolution JPEG images to estimate fingerprint $\hat{K}$

Experiment Setup

Classification:

Set of binary SVM classifiers were used to perform multi-classification (voting system).

Features:

We propose set of 28 features calculated from camera fingerprint $\hat{K}$.

Feature selection using BAHSIC:

Reduce the number of features based on Hilbert-Schmidt Independence Criterion (HSIC).

Finally we used only 5 features for classification.

Final Results - Blind Camera Model Identification

		C1	C2	C3	F1	K1	K2	M1	N1	N2	N3	O1	O2	P1	P2	P3	S1	S2
Canon PS S3	C1	69.4	*	22.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Canon PS SD400	C2	*	95.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Canon PS SD600	C3	22.6	*	65.2	*	*	*	*	*	*	5.8	*	*	*	*	*	*	*
Fuji Finepix A345	F1	*	*	*	93.4	*	*	*	*	*	*	*	*	*	*	*	*	*
Kodak CX7300	K1	*	*	*	*	94.6	*	*	*	*	*	*	*	*	*	*	*	*
Kodak Z740 Zoom	K2	*	*	*	*	*	98.2	*	*	*	*	*	*	*	*	*	*	*
Minolta Dimage XT	M1	*	*	*	*	*	*	79.8	10.6	*	8.2	*	*	*	*	*	*	*
Nikon Coolpix 3200	N1	*	*	*	*	*	*	6.8	82.2	*	5.6	*	*	*	*	*	*	*
Nikon Coolpix 4300	N2	*	*	*	*	*	*	*	*	85.5	3.9	3.9	*	*	*	*	*	*
Nikon Coolpix 4600	N3	*	*	*	*	*	*	5.8	8.3	*	71.2	8.2	*	*	*	*	*	*
Olympus C350z	O1	*	*	*	3.2	*	*	*	3.2	*	8.4	77.8	*	*	*	*	*	*
Olympus S300	O2	*	*	*	*	*	*	*	*	*	*	*	96.2	*	*	*	*	*
Panasonic DMC-FX01	P1	*	*	*	*	*	*	*	*	*	*	*	*	90.9	*	*	*	*
Panasonic DMC-FX7	P2	*	*	*	*	*	*	*	*	*	*	*	*	*	95.9	*	*	*
Panasonic DMC-FZ7	P3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	90.3	*	*
Sony DSC-P200	S1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	93.4	*
Sony DSC-W50	S2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	96.1

Confusion matrix in % obtained as an average over 8 experiments. We used $m = 45$ images to estimate $\hat{K}$.
$*$ represents values smaller than 3%.

Final Results - Blind Camera Brand Identification

	C	F	K	M	N	O	P	S
Canon C	93.47	*	*	*	3.46	*	*	*
Fujifilm F	2.5	93.39	*	*	*	*	*	*
Kodak K	*	*	96.45	*	*	*	*	*
Minolta M	*	*	*	79.79	18.88	*	*	*
Nikon N	2.35	*	*	4.35	86.16	5.12	*	*
Olympus O	*	*	*	*	7.11	87.29	*	*
Panasonic P	*	*	*	*	*	*	94.44	*
Sony S	*	*	*	*	*	*	*	95.97

Confusion matrix in % obtained as an average over 8 experiments. We used $m = 45$ images to estimate $\hat{K}$.
$*$ represents values smaller than 2%.

Conclusion

- Camera brand (and/or model) can be determined from the PRNU based camera fingerprint.
- Results were obtained by using a large number of different physical cameras to avoid over-training.
- Average probability of correctly classified camera brand was 90.8%.
- This tool complements other approaches.

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- Camera brand (and/or model) can be determined from the PRNU based camera fingerprint.
- Results were obtained by using a large number of different physical cameras to avoid over-training.
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- This tool complements other approaches.

Thank you!

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Available camera models

Camera model	# of cameras	Sensor size (MPix)
Canon PowerShot S3 IS	465	6.0
Canon PowerShot SD400	647	5.0
Canon PowerShot SD600	213	6.0
Fujifilm FinePix A345	140	4.0
Kodak CX7300	150	3.2
Kodak Z740 Zoom	245	5.0
Minolta DiMAGE XT	117	3.1
Nikon Coolpix 3200	352	3.1
Nikon Coolpix 4300	262	3.9
Nikon Coolpix 4600	394	3.9
Olympus C350 Zoom	101	3.1
Olympus Stylus 300	320	3.1
Panasonic DMC-FX01	246	6.0
Panasonic DMC-FX7	119	4.9
Panasonic DMC-FZ7	241	6.0
Sony DSC-P200	283	7.1
Sony DSC-W50	270	6.0