Additive spread-spectrum watermark detection in demosaicked images

Peter Meerwald, Andreas Uhl

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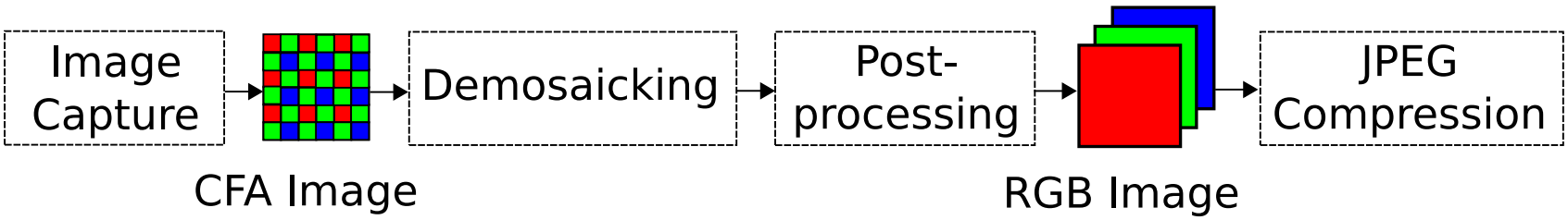
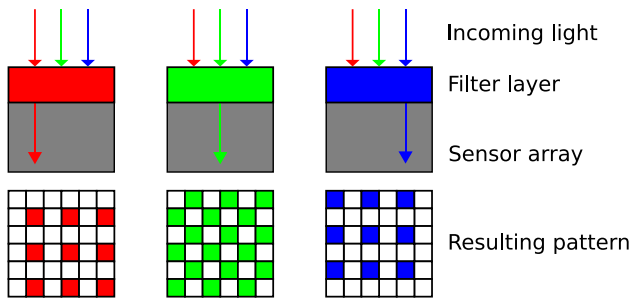
Overview

- Camera image processing pipeline and demosaicking
- Watermark embedding in sensor data (implemented in camera firmware)
- Detection using fused polyphased components
- Assessment of demosaicking impact on watermark detection
- Conclusions

Camera Image Processing Pipeline



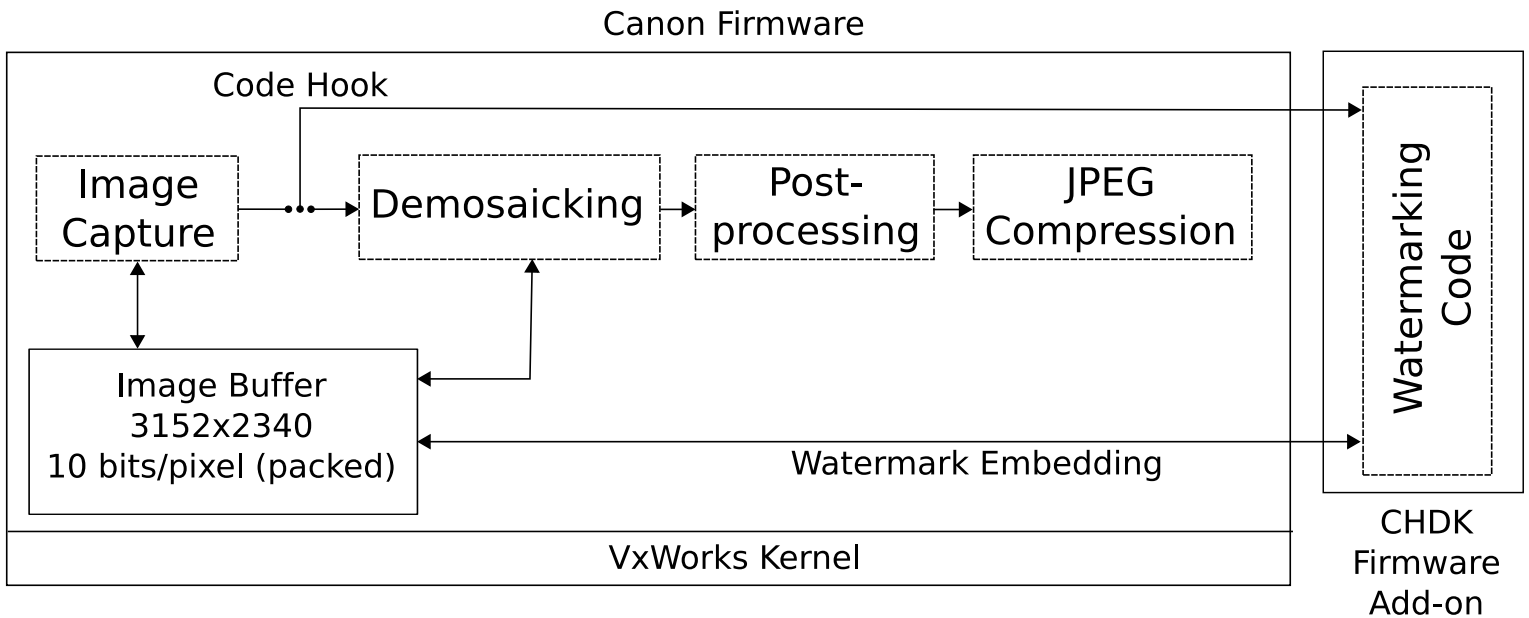
- Most cameras use single image sensor with color filter array (CFA)



- Demosaicking is basically interpolation to get full-resolution RGB image
- Many different demosaicking approaches exist (bicubic, gradient-based, adaptive homogeneity-directed, . . .)
- Actual camera implementation is unknown

Watermark Embedding in Camera Firmware [Meerwald and Uhl, 2009]

- Straightforward additive embedding in sensor data
- CHDK: open-source firmware add-on for Canon DIGIC II and DIGIC III cameras, `http://chdk.wikia.com`
  - Targets ARM9 CPU core with custom hardware
  - Provides Linux-hosted cross-compilation system, using arm-elf-gcc 3.4.6
- Implemented for Canon IXUS 70 and PowerShot A720



Watermarking Firmware in Action

- On-screen menu allows to set watermark embedding strength and watermark key

Related work

- [Nelson et al., 2005] propose to embed additive watermark in CMOS sensor hardware
- JPEG compressed-domain watermarking, but does not protect the raw sensor data
- Forensic techniques
  - using PRNU for camera identification [Chen et al., 2008]
  - CFA interpolation pattern for authentication [Popescu and Farid, 2005]

Embedding and Detection Strategies

- Watermarking CFA sensor data (raw image) because
  - it contains all information and may therefore be archived
  - all copies of a scene shot shall carry the same watermark
- Watermark embedding is constrained by processing resources of the camera, hence
  - only additive embedding in pixel data (no transform or perceptual modelling)
  - investigate green or blue pixel watermarking
- Demosaicked image is highly correlated (intra- and inter color channel) – useful for detection?

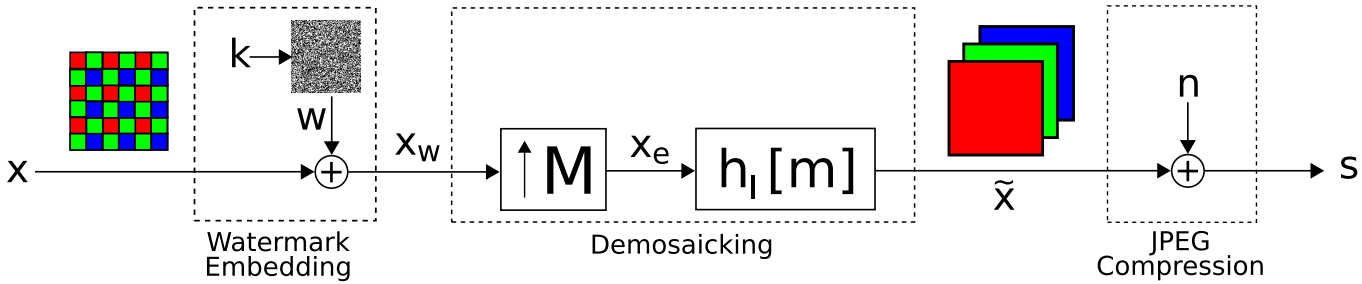
Demosaicking

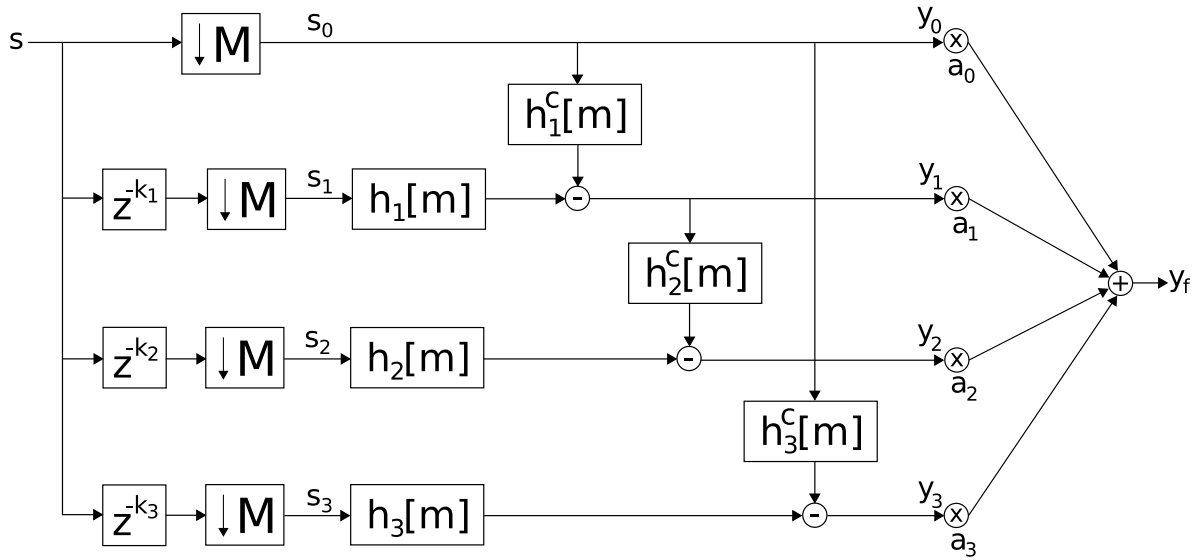
- Intra-only demosaicking (separate processing of each color channel) : bilinear, edge-directed interpolation, ...
- Sequential inter-channel interpolation (spatial and frequency domain): first reconstruct green channel to guide interpolation of red and blue channel
- Parallel inter-channel interpolation
- Impact on watermark detection?

Intra	Sequential Inter Channel Interpolation	
	Spatial Domain	Frequency Domain
bilinear, EDI [17]	ACPI [12], DAF [21], DF [23], DLMMSE [34], ECI [27], JDD [35], LPA [26], NCRM [20], NM [19], PCD [33], SA [15], SSC [4], TSD [31], VCD [6]	AF [18], AHD [13], AP [11], FD [9], FHVS [1]

Detection using Fused Polyphase Components

Exploit intra- and inter-channel correlation in demosaicked image using detection framework for noisy, interpolated images [Giannoula et al., 2006]





Linear Correlation Detection on Fused Image

Step 1: Compute fused image by weighted addition of polyphase components

- s_0 : using only one polyphase component, no fusion
- y_f : intra color-channel component fusion [Giannoula et al., 2006]
- y_{cf} : inter color-channel component fusion

Step 2: Linear Correlation (LC) detection on fused image

- Pre-filtering LC: $\rho_{pf} = \frac{1}{N} \sum_{\mathbf{m}} (h_{wf} * s_0)[\mathbf{m}] \cdot w[\mathbf{m}]$
- Fused LC: $\rho_f = \frac{1}{N} \sum_{\mathbf{m}} y_f[\mathbf{m}] \cdot w[\mathbf{m}]$
- Color-fused LC: $\rho_{cf} = \frac{1}{N} \sum_{\mathbf{m}} y_{cf}[\mathbf{m}] \cdot w[\mathbf{m}]$
- Pre-filtered Color fused LC (with pre-filtering): $\rho_{pfcf} = \frac{1}{N} \sum_{\mathbf{m}} (h_{wf} * y_{cf})[\mathbf{m}] \cdot w[\mathbf{m}]$

Detection Results

330 different watermarks per image, 12 images

22 demosaicking methods, JPEG compression Q=20...100

probability of false alarm $P_f = 10^{-4}$

6272640 detection attempts (H_0 and H_1)

Method	Blue Channel Watermark				Green Channel Watermark			
	F-LC	CF-LC	PF-LC	PFCF-LC	F-LC	CF-LC	PF-LC	PFCF-LC
bilinear	38.92	39.97	**26.50**	26.60	5.63	3.24	1.79	**1.72**
EDI	32.57	37.77	**31.68**	32.21	1.13	**0.82**	0.91	0.91
none	44.07	44.37	**42.25**	42.27	15.39	9.97	9.34	**8.98**
ACPI	16.21	15.78	7.09	**6.95**	1.75	**0.52**	0.85	0.76
DAF	20.90	17.21	3.57	**3.38**	4.45	2.12	1.38	**1.25**
DF	11.38	9.79	3.84	**3.64**	2.47	**0.83**	1.40	1.24
DLMMSE	13.24	11.34	4.08	**3.95**	2.09	**0.62**	1.11	0.98
ECI	13.26	12.6	5.55	**5.33**	1.57	**0.52**	0.84	0.77
JDD	16.67	14.62	5.29	**5.16**	4.61	**2.04**	2.66	2.45
SA	7.79	5.20	2.54	**2.39**	3.64	**1.53**	1.82	1.66
LPA	11.93	10.08	3.97	**3.83**	2.47	**0.79**	1.36	1.21
NCRM	10.41	11.54	4.23	**3.97**	5.18	2.48	1.21	**1.11**
NM	15.93	15.13	6.23	**6.05**	1.56	**0.46**	0.80	0.71
PCD	19.17	17.42	5.51	**5.33**	3.08	1.03	0.98	**0.87**
SSC	7.00	6.93	3.35	**3.16**	3.71	1.59	1.46	**1.33**
TSD	9.39	7.21	3.01	**2.84**	2.89	**1.11**	1.55	1.42
VCD	24.47	20.31	3.62	**3.49**	7.23	3.93	1.35	**1.25**
AF	10.78	8.88	3.71	**3.50**	2.77	**1.05**	1.53	1.40
AHD	14.83	13.78	5.97	**5.79**	1.09	**0.27**	0.60	0.53
AP	38.38	39.77	24.92	**24.65**	11.72	6.17	2.61	**2.49**
FD	8.60	6.39	2.72	**2.54**	0.54	**0.25**	0.43	0.35
FHVS	9.81	7.33	2.80	**2.55**	2.75	**1.10**	1.73	1.63

Conclusion

- Raw image data is probably the most valuable image asset, but few prior work on its watermarking
- In this work:
  - Assessed the impact of demosaicking on additive, spatial-domain watermark in green and blue CFA sensor data
  - Utilized [Giannoula et al., 2006] detection framework and extended to color component fusion
- Open questions:
  - Efficient perceptual modelling, modelling of host noise (e.g. Cauchy [Sayrol et al., 1999])
  - ...
- Source code of watermarking firmware add-on and watermark detector(s) available: `http://www.wavelab.at/sources`

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