Camera Characterization for Multiple Imaging Modes Extending the EMVA 1288 Standard

Bernd Jähne

Chair EMVA 1288 and Board Member EMVA
Heidelberg Collaboratory for Image Processing (HCI)
Heidelberg University, Germany
jaehne@emva.org

AIT Scientific Vision Days
Vision, Stuttgart, November 11, 2018

1288 EMVA Standard Compliant

Types of multi-modal imaging sensors

Increasing number of multi-modal imaging sensors

- UV and SWIR imaging
- Classical RGB and RGB+NIR image sensors
- Multi-spectral image sensors
- Polarization image sensors
- Combination of color and polarization image sensors
- Time-of-flight image sensors
- ...

Common to all of these multi-modal image sensing:

- Multiple channels
- Information of interest is not intensity in individual channel, but parameters derived from multiple channels

1288 EMVA Standard Compliant

Polarization Imaging

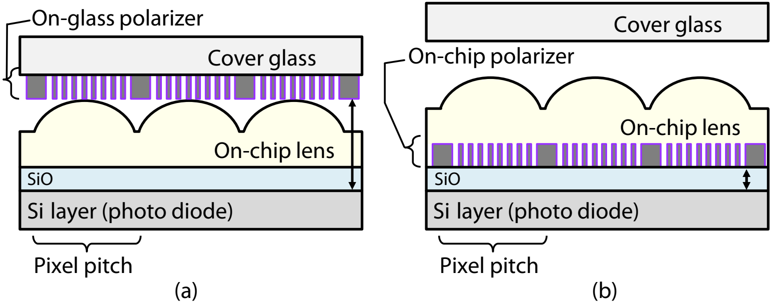


Fig. 3. Device structures of pixel-wise polarizers: (a) Conventional structure. (b) Pixel-wise on-chip polarization image sensor.

Source: Yamazaki et al., 2016

New polarization image sensors with on-chip polarizers are now available by Sony

1288 EMVA Standard Compliant

On-Chip Polarizers

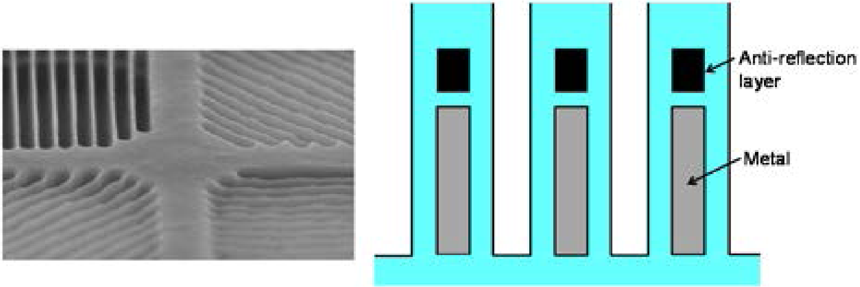


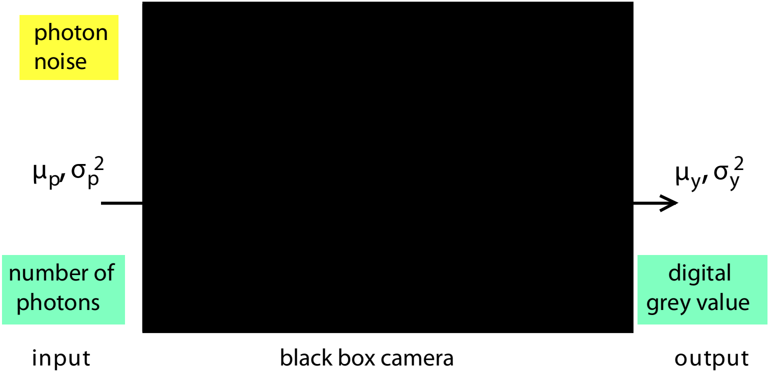
Fig. 5. Photograph and cross-sectional structure of the wire grid.

Quelle: Yamazaki et al., 2016

2×2 array of polarization filters in 0, 45, 90 und 135 degree as wire grids with air spaces
Sony Technology demo in 2016 with 2.5 μm pixel
Now available: Sony Pregius IMX250MZR

1288 EMVA Standard Compliant

How Does EMVA 1288 Measure Signal Quality?

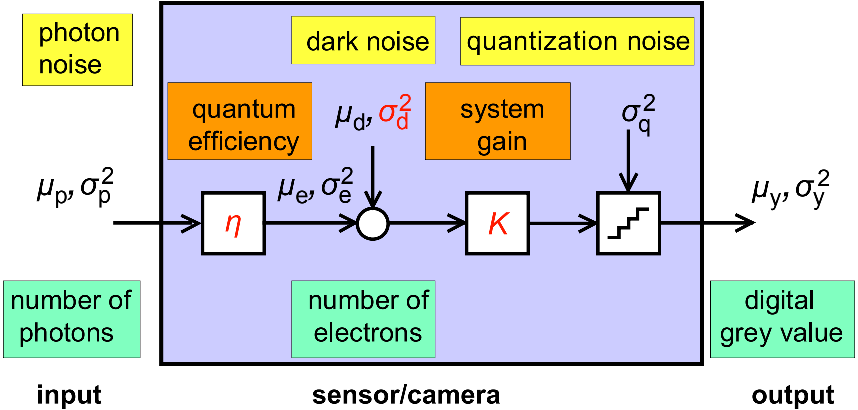


System-theoretical approach with camera as black box (No internal measurements!)

- input: mean number of photons μ_p hitting pixel during exposure time
- output: mean digital gray value μ_y and its variance σ_y^2

1288 EMVA Standard Compliant

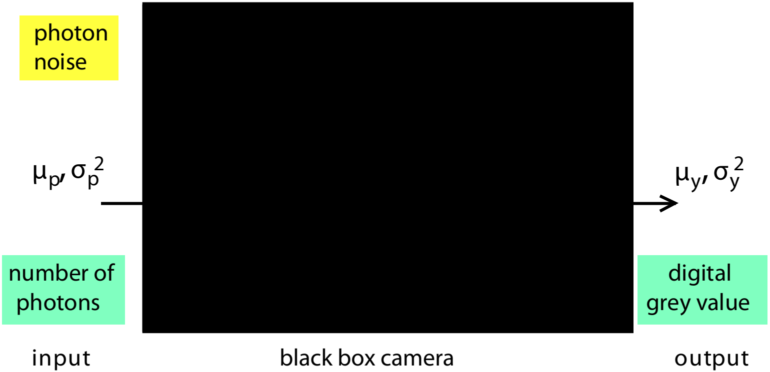
Linear Model



Model parameters quantum efficiency η, dark noise σ_d, and system gain K

1288 EMVA Standard Compliant

No Model



Even without a model most important characteristics can be measured:

- Characteristic (sensitivity) curve $\mu_y = f(\mu_p)$
- Photon transfer curve $\sigma_y^2 = g(\mu_p)$
- Output signal-to-noise ratio $\mathrm{SNR}_{\mathrm{out}} = \mu_y / \sigma_y$

1288 EMVA Standard Compliant

EMVA 1288 for New Modes Of Imaging

EMVA 1288 measurements can simply be extended provided

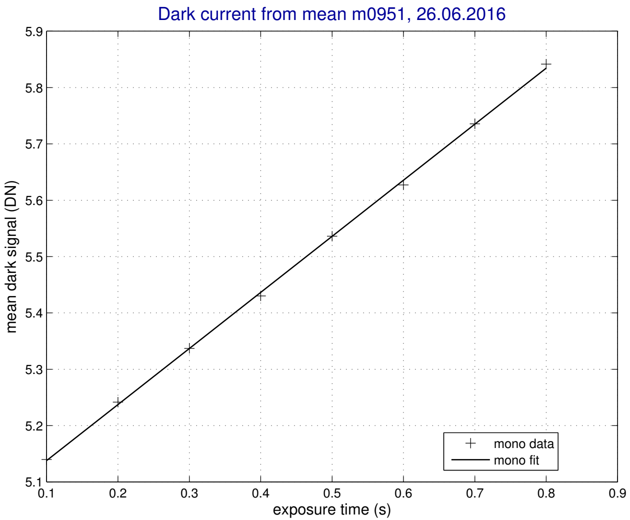
- Linear model still applies
- Usage of appropriate light source with proper wavelength
- Apply EMVA 1288 measurements to each channel of multi-modal sensors individually

Caveats:

- In deep UV more than one charge unit may be generated per photon
- Much higher dark current in SWIR requires more detailed analysis
- Additional measurements may be required
- Too many channels: simplified measurements are required

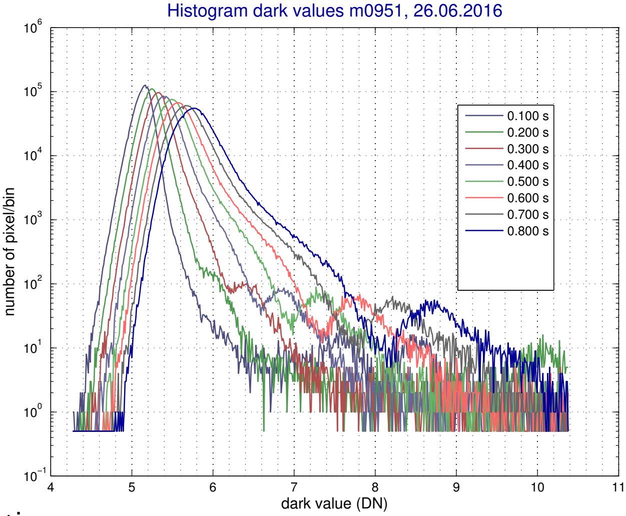
1288 EMVA Standard Compliant

Standard Mean Dark Current Measurements



no longer sufficient

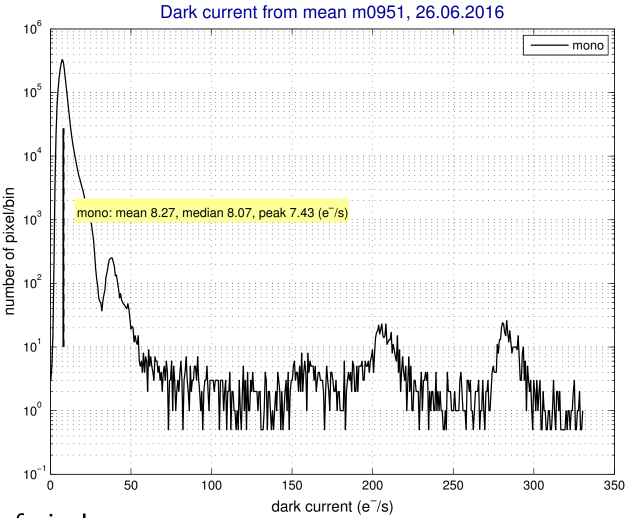
Dark Value Histograms



for different exposure times

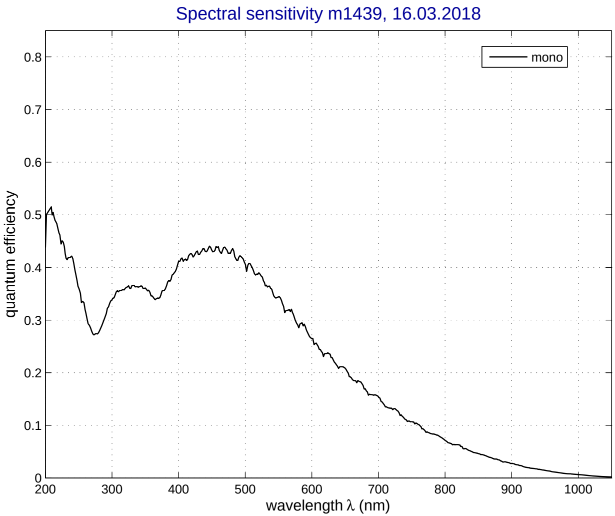
1288 EMVA Standard Compliant

Histograms of dark current measured for each pixel



reveal different types of pixels

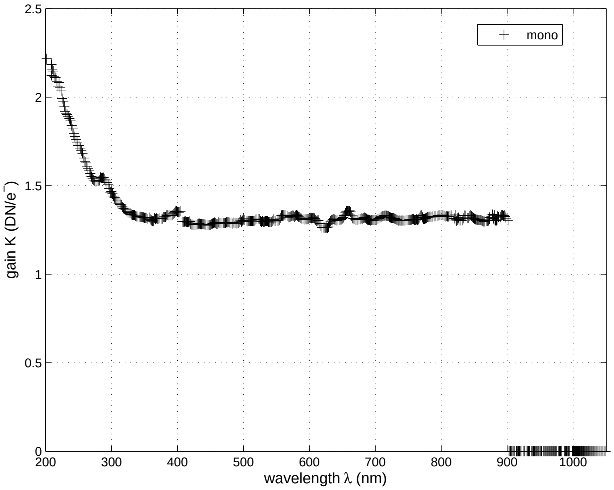
UV Spectral sensitivity



Measurement of quantum efficiency η down to 200 nm for pco.uv camera with UV-sensitive Sony interline CCD sensor

1288 EMVA Standard Compliant

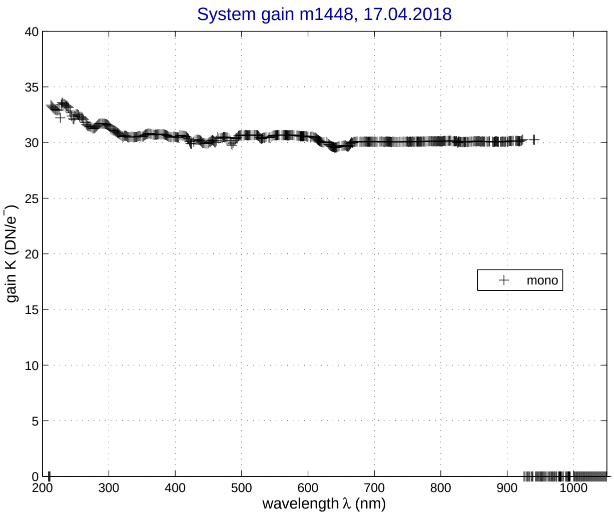
UV excess noise



Excess noise by generation of more than one charge unit by one photons observed by wavelength-dependent system gain K

1288 EMVA Standard Compliant

UV excess noise



Excess noise strongly depends on sensor architecture, here Tucson Dhyana with Gpixel back-illuminated sCMOS sensor Gsense400BSI

Derived Parameters from multi-modal imaging

Example polarization imaging: linear degree of polarization P and polarization angle θ most important derived quantities

Can be computed from first three components of Stokes vector:

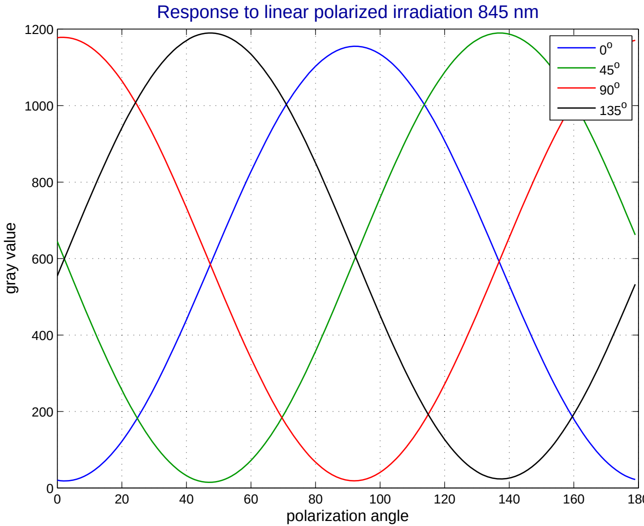
$$\boldsymbol{S}_l = \begin{bmatrix} S_0 \\ S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} I_0 + I_{90} \\ I_0 - I_{90} \\ I_{45} - I_{135} \end{bmatrix}$$

Requires polarization camera with linear polarization filters in four directions 0, 45, 90, and 135 degree (three directions would also be sufficient, see Bauer, 2013)

$$P = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}, \qquad \tan\theta = \frac{S_2}{S_1}$$

1288 EMVA Standard Compliant

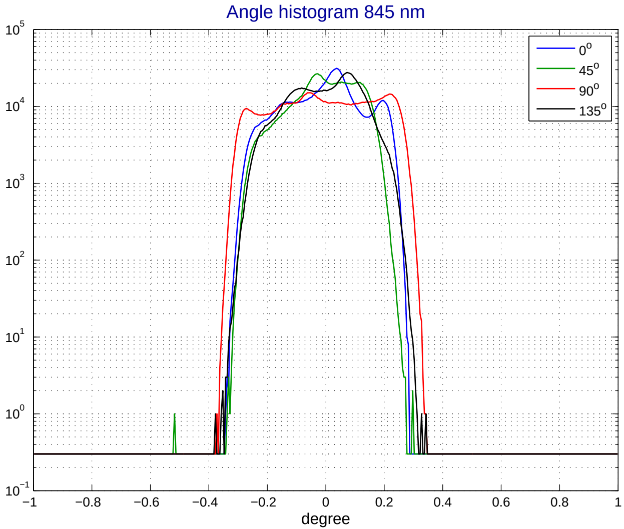
Mean Response



to linear polarized light: $I_{ampl} cos^2(\theta - \theta_0) + I_0$

1288 EMVA Standard Compliant

Nonuniformity



Logarithmic histogram for **angle** polarization filters, $\sigma_\theta = 0.12^o, 0.10^o, 0.16^o, 0.11^o$

1288 EMVA Standard Compliant

Conclusions

- System theoretic approach of EMVA 1288 standard makes it easy to extend to new imaging modalities
- EMVA 1288 needs to extended to more detailed dark current analysis for all types of sensors (UV, VIS and SWIR)
- Derived parameters can be included by extending EMVA 1288 model
- Rich set of tools to analyze all kinds of non-uniformities also suitable for derived parameters

- UV, SWIR and polarization imaging will be included in next release of EMVA 1288
- Multispectral and hyperspectral imaging: cooperation with working group P4001 of IEEE (led by NIST and Labsphere Inc., USA)

1288 EMVA Standard Compliant

Where to Learn More

- Standard documents & data sheets
  https://zenodo.org/collection/user-emva1288
- Free EMVA 1288 Webinars provided by EMVA
  https://www.viewservice.de/emva-webinar/
- EMVA 1288 Seminars (German & English):
  - Framos, Munich, December 5–6, 2018
    https://www.framos.com
  - AEON, Hanau, March 27–28, 2019
    www.aeon.de/en/emva-1288.html

1288 EMVA Standard Compliant

Literature I

[1] P. Bauer.
Development of an imaging polarimeter for water wave slope measurements.
Masterarbeit, Universität Heidelberg, 2013,
http://dx.doi.org/10.11588/heidok.00015899.

[2] European Machine Vision Association (EMVA).
EMVA Standard 1288. Standard for Characterization of Image Sensors and Cameras.
Release 3.0, November 26, 2010, Release 3.1, December 30, 2016
www.standard1288.org

[3] T. Yamazaki et al.
Four-directional pixel-wise polarization CMOS image sensor using air-gap wire grid on 2.5-μm back-illuminated pixels
2016 IEEE International Electron Devices Meeting (IEDM),
http://dx.doi.org/10.1109/IEDM.2016.7838378

1288 EMVA Standard Compliant