Photometric Calibration of High Dynamic Range Cameras

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Introduction

We focus here on the specific challenges posed by the photometric calibration of cameras with a dynamic range of more than six orders of magnitude such as complex camera response curves or selection of appropriate calibration targets.

HDR cameras

HDRC VGAx CMOS sensor with logarithmic response (10-bit)

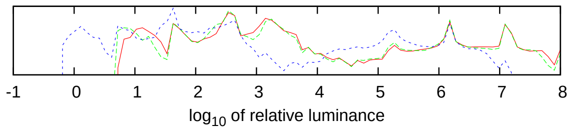
Silicon Vision LarsIII sensor with locally autoadaptive exposure (16-bit)

Jenoptik C14 high-end CCD based LDR camera (14-bit)

Calibration Target

Three scenes stitched together with a total dynamic range of 8 orders of luminance magnitude.

Three acquisitions: without filter, using a neutral density filter with $\times 1.5$ and $\times 10$ extension factors.



Response Recovery

The response curve is recovered from the three exposures of the calibration target using the Robertson at al. [2003] approach. The approach is based on the following observation:

$$y_{ij} = f(t_i * x_j + N^c_{ij}) \tag{1}$$

The response is estimated through the optimization:

$$\tilde{O}(f, x) = \sum_{i,j} w_{ij} * (f^{-1}(y_{ij}) - t_i * x_j) \tag{2}$$

where:
f camera response function; y_{ij} camera output value for j^{th} pixel of i^{th} exposed image; t_i exposure time; x_j underlying light value; N^c_{ij} noise term; w_{ij} weighting function;

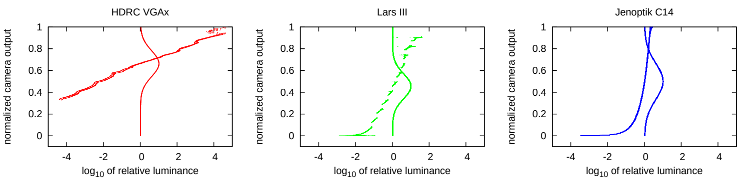
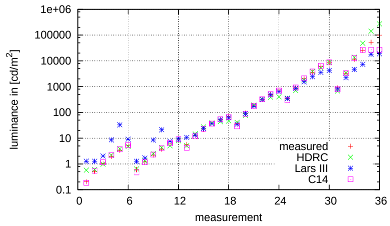


Figure 1: The recovered response curves with weights.

Absolute Calibration

The fit of the recovered response curves to the measurements of 6 gray patches of GretagMacbeth ColorChecker chart under 6 different illumination conditions.



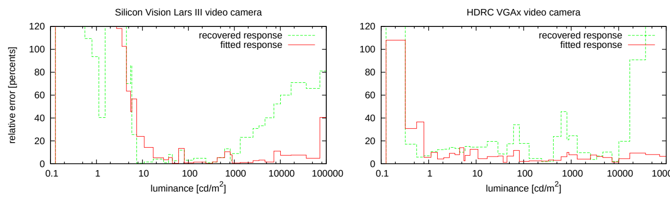
Alternative photometric calibration
$\rightarrow$ fit an a priori function to the measurements:

HDRC VGAx: $y_j = a * \log_{10}(x_j) + b$

Silicon Vision LarsIII: $y_j = a * x_j + b$.

Results

The relative errors in luminance measurement achieved by the response curve recovery including absolute calibration compared to the function fitting:



Measured luminance values of patches with corresponding camera output and calibrated camera response obtained via response recovery and function fitting:

measured luminance $[cd/m^2]$	HDRC output 10 bit	HDRC recovered resp. $[cd/m^2]$	HDRC fitted resp. $[cd/m^2]$	Lars III output 16 bit	Lars III recovered resp. $[cd/m^2]$	Lars III fitted resp. $[cd/m^2]$	C14 recovered resp. $[cd/m^2]$
5.3	404	4.78	4.57	200	9.04	8.69	5.38
9.3	424	7.95	8.12	366	9.35	11.52	9.05
70.9	497	46.70	62.65	3,278	62.46	61.33	66.07
741.2	582	403.22	695.22	18,722	643.96	663.00	704.43
8,796	673	8,616.82	8,924.89	32,126	4,196.72	7,822.66	8,734.86
194,600	788	1,081,800	225,010	43,665	44,121,000	50,415	-

Conclusions

- HDR cameras can be used for photometric measurements
- Response curve recovery helps to understand the sensor technology
- Lower relative error with the function fit approach
- Response recovery gives confidence in the choice of an a priori function
- Function fit allows for an extrapolation of the data
- Limited precision may be due to the sensor noise or the glare artifacts introduced by the ND filters

References

[Robertson et al. 2003] Estimation-theoretic Approach to Dynamic Range Enhancement Using Multiple Exposures. *Journal of Electronic Imaging*, April 2003.