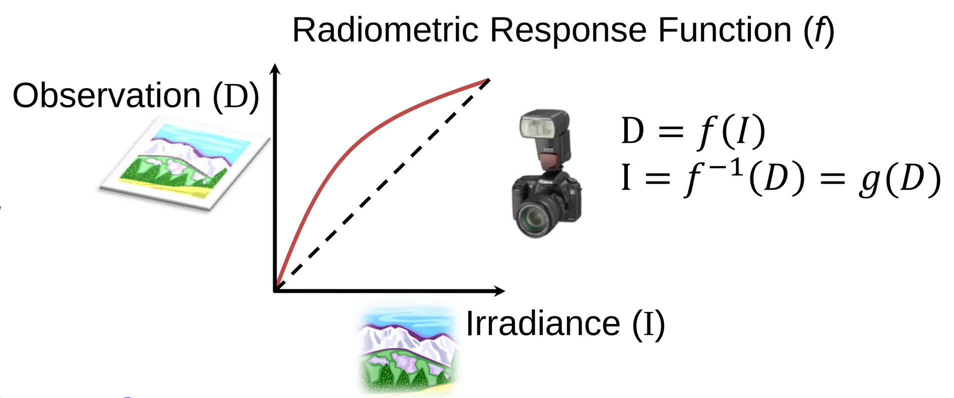
Radiometric Calibration by Transform Invariant Low-rank Structure

Joon-Young Lee[1] Boxin Shi[2] Yasuyuki Matsushita[3] In-So Kweon[1] Katsushi Ikeuchi[2]

[1] Robotics and Computer Vision Lab, KAIST, Korea [2] The University of Tokyo, Japan [3] Microsoft Research Asia, China

Radiometric Calibration

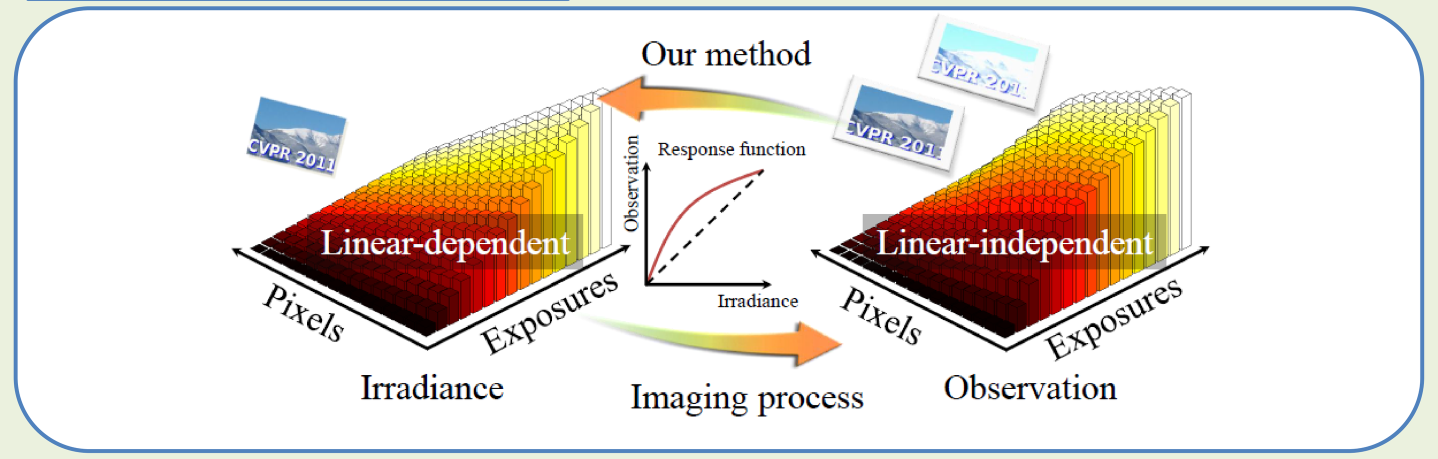
- ➢ Radiometric calibration aims at recovering the *inverse response function.*



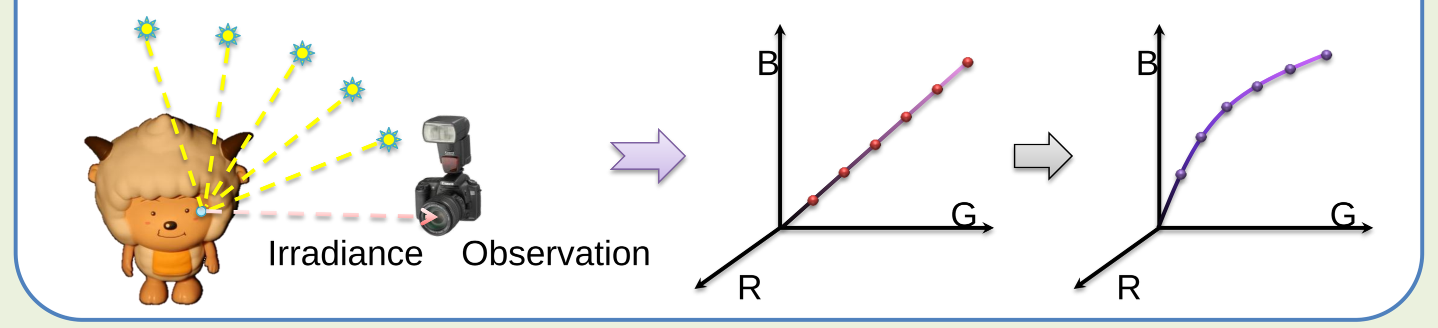
Transform Invariant Low-rank Structure

- ➢ Radiometric calibration problem as low-rank recovery problem
- ➢ **An irradiance matrix has a low-rank structure**

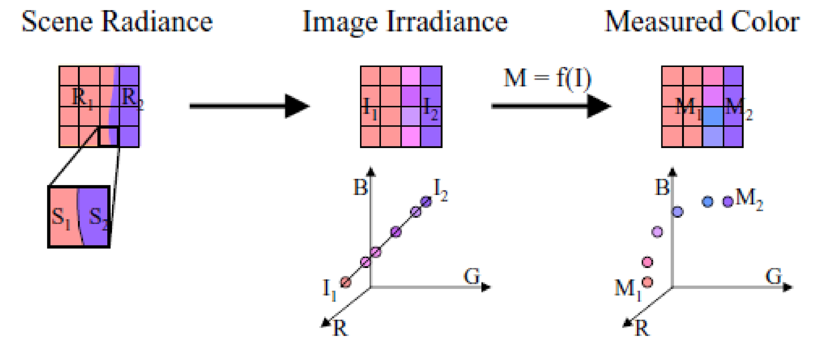
Multiple exposure case — Mitsunaga and Nayar, CVPR 1999



Varying illumination case — Shi *et al*, CVPR 2010



Irradiance mixture case — Lin *et al*, CVPR 2004



This part is not included in the current paper.

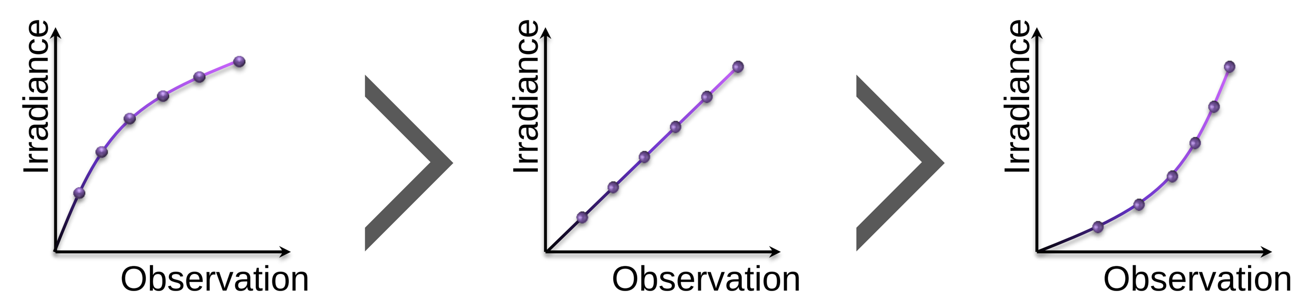
Rank minimization

$$\hat{g} = \underset{g}{\operatorname{argmin}}\ \operatorname{rank}(A) \quad \text{s.t.} \quad A = g \circ D$$

Calibration Algorithm

- ➢ Rank minimization → Nuclear norm (sum of the singular values) minimization
- ➢ Response function changes not only the rank, but also the nuclear norm

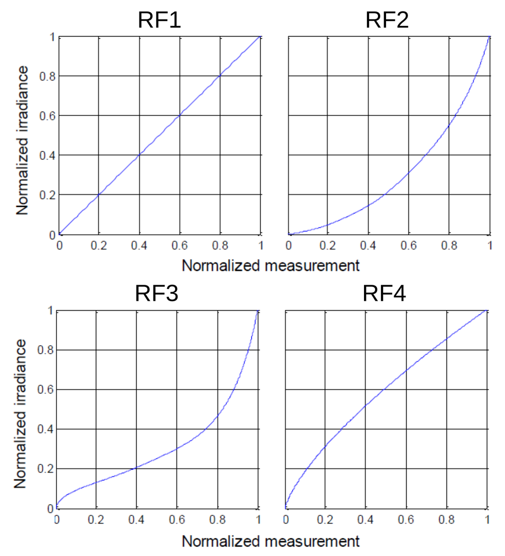
The nuclear norm changes after applying different inverse response functions



- ➢ We minimize the condition numbers (a ratio of singular values)

- ➢ Main factors causing rank variations
  - • Nonlinearity of response function
    - – Low-frequency nature: monotonic and smooth characteristics of response functions
    - – **Only 2nd condition number has large value**
  - • Image noise
    - – High-frequency nature: zero mean Gaussian random noise
    - – **All the condition numbers are evenly affected**

condition number		κ_2	κ_3	κ_4	κ_5
without noise	RF 1	0.0000	0.0000	0.0000	0.0000
	RF 2	0.0289	0.0034	0.0010	0.0005
	RF 3	0.1163	0.0177	0.0025	0.0001
	RF 4	0.0029	0.0000	0.0000	0.0000
with noise ($\sigma = 0.005$)	RF 1	0.0079	0.0077	0.0075	0.0072
	RF 2	0.0293	0.0059	0.0050	0.0048
	RF 3	0.1120	0.0175	0.0054	0.0046
	RF 4	0.0094	0.0087	0.0085	0.0081



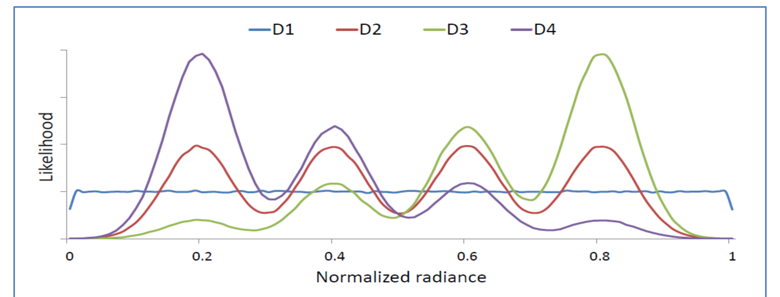
- ➢ Cost function

$$\hat{g} = \underset{g}{\operatorname{argmin}} \boxed{\kappa_2(A)} + \lambda \sum_t H\left(-\frac{\partial g(t)}{\partial D}\right) \quad \text{s.t.} \quad A = g \circ D$$

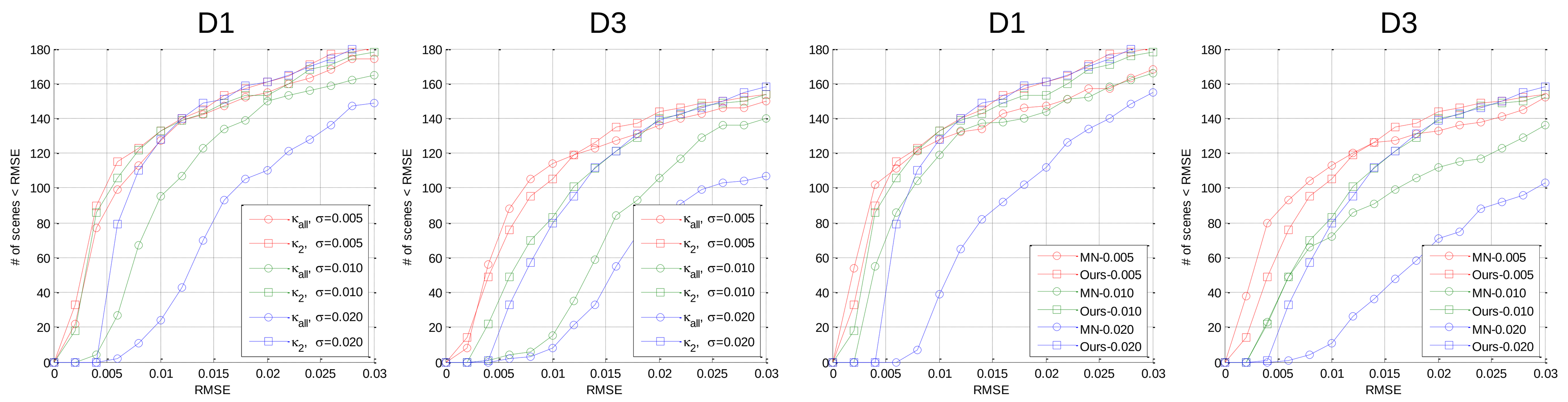
g: inverse response function, **D**: observation matrix
H(x)=1 if x≥0, otherwise H(x)=0

Experiments

- ➢ Simulation of multiple exposure input
  - • 201 response functions in DoRF
  - • 4 radiance distributions
  - • Gaussian noise with σ(=0, 0.005, 0.010, 0.020, 0.030)



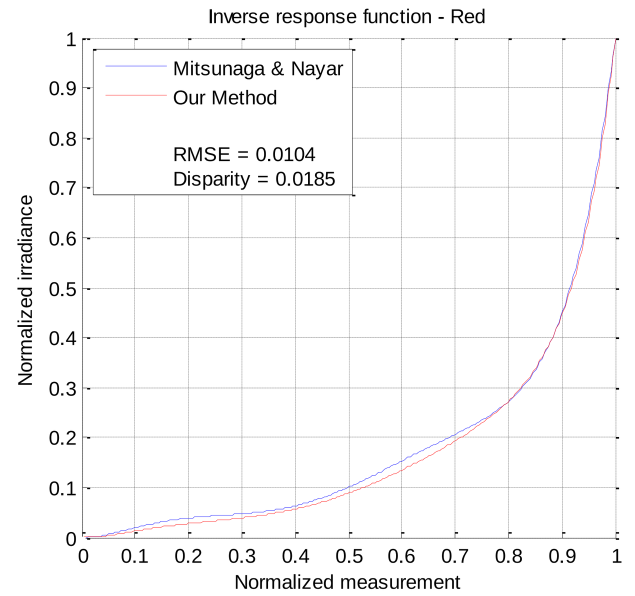
4 radiance distributions



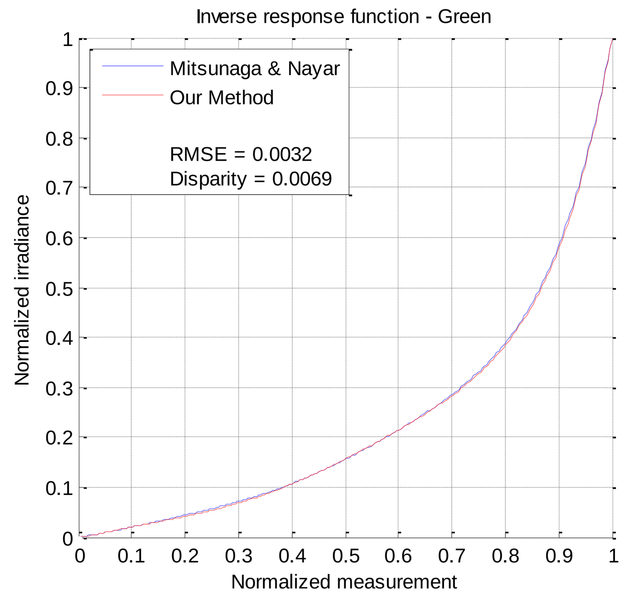
$\min \sum \kappa_i \quad vs. \quad \min \kappa_2$

Results of synthetic experiments

- ➢ Real-world experiment



Canon 20D



Olympus E1

Conclusions

- ➢ We introduce radiometric calibration algorithm that use low-rank structure of irradiance matrix
- ➢ Radiometric calibration is formulated as rank minimization and solved by the condition number minimization
- ➢ Our method can avoid over-fitting
- ➢ Our method can be applied to various kind of radiometric calibration problems