Physical High Dynamic Range (HDR) Imaging with Conventional Sensors

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Scenario and Goal

Goal: Simplified high dynamic range (HDR) image generation

- Scenario: Dynamic range of scene is larger than dynamic range of sensor
- Common HDR: exposure bracketing ⇒ several shots
  - ⇒ Long total acquisition time
  - ⇒ Ghosting likely to occur
  - ⇒ Challenging free-hand shots
- HDR image generation from several low dynamic range (LDR) images may be challenging and computationally complex

Underexposed ⇒ highlights OK — Overexposed ⇒ shadows OK

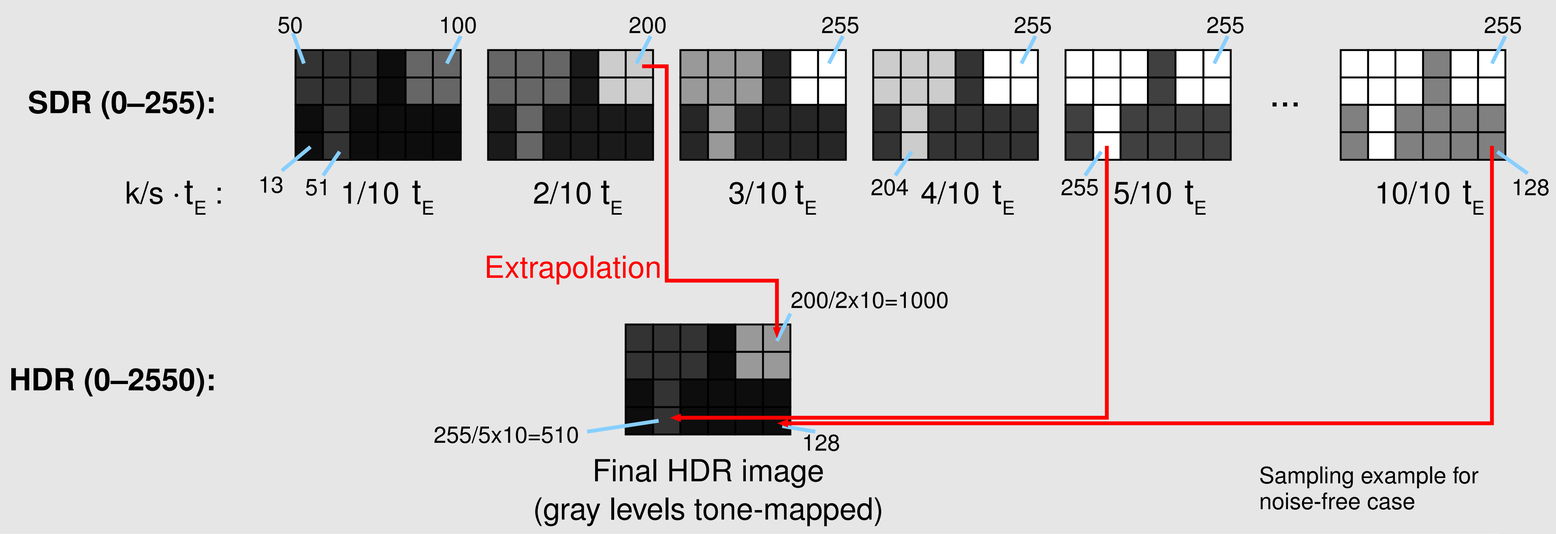
Idea: Sampling during exposure

Sampling during Exposure

- Consider only pels below saturation for each sampling step
- Pel-wise temporal extrapolation
- Pel-wise averaging of temporally extrapolated pels

Improvement for noise reduction:

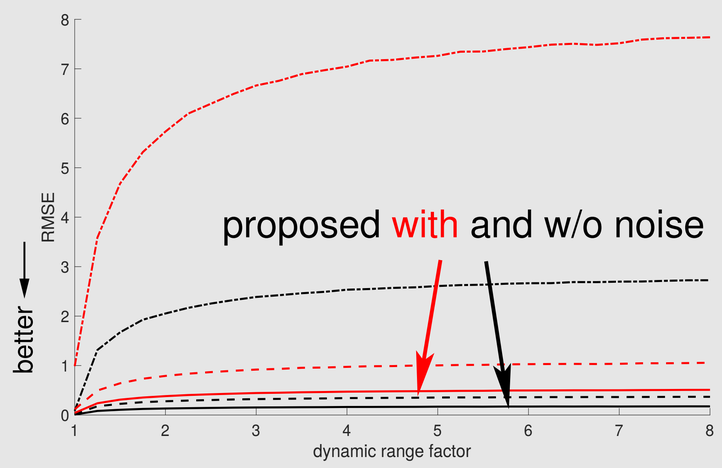
- Weighted averaging of temporally extrapolated samples



Total acquisition time $t_E \ll t_{total,common}$ ⇒ ghosting artifacts less likely to occur

Error Analysis

- Rounding error for each intermediate sampling step: $|e| \leq \frac{1}{2}$
- Rounding error after extrapolation from k-th out of s sampling steps: $|e_k| \leq \frac{s}{2k}$
- Error for noise-free case: $e_k = \left|\bar{v}(x, y, t_E) - g_k\right|$,
  with $\bar{v}(x, y, t_E)$: non-measurable, true value for pixel (x, y) after total exposure time t_E,
  $g_k = \frac{s}{k} \cdot \left[\frac{k}{s} \cdot \bar{v}(x, y, t_E)\right]$: extrapolated value, $[\cdot]$: rounding function
- Error with zero-mean white Gaussian noise: $e_k \leq \left|\bar{v}(x, y, t_E) - \left(g_k + \frac{s}{k}\,[\eta_k]\right)\right| + \nu_k$
  with η, g, ν: random variables with realizations η_k, g_k, $\nu_k = \frac{s}{k} \cdot 1$



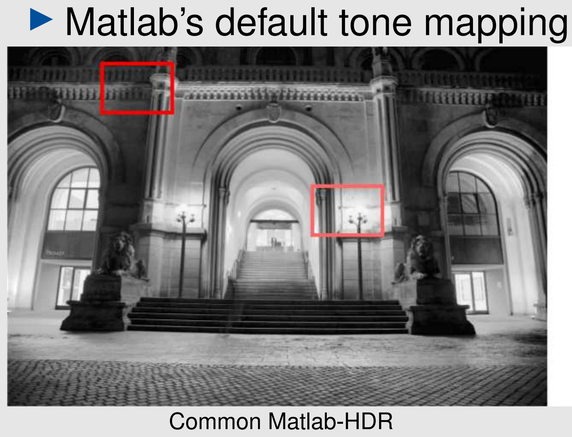
Black lines: noise-free ($\sigma = 0$); red lines: w/ noise $\sigma = 3$.
Dash-dotted: naïve extrapolation; dashed: temporal averaging; solid: weighted averaging

Temporal averaging and weighting for noise-reduction

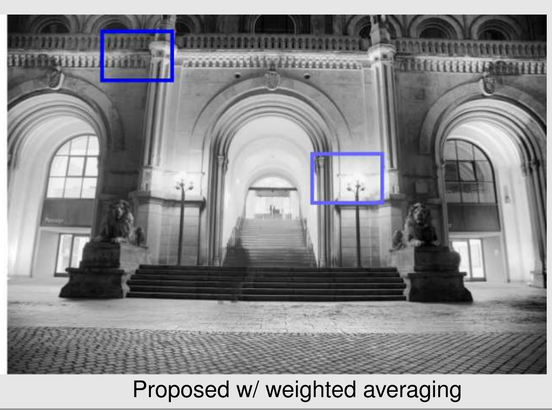
- Extrapolated rounding errors and noise decrease for later sampling steps, but **all** sampling steps are affected by independent noise ⇒ temporal averaging
- Signal-to-noise ratio (SNR) increases for longer exposure times
  ⇒ higher weighting of later sampling values, e. g. with weighting function $w_k = \frac{k}{\sum_{j=1}^{s} j}$

Experimental Results

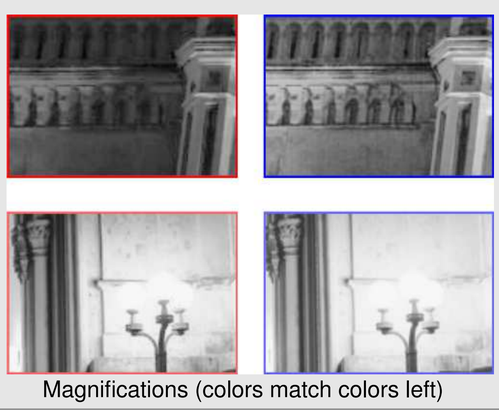
- 10 intermediate samplings simulated by taking 10 photos with increasing exposure times
  ⇒ worst-case due to independent noise and rounding in each photo
- Matlab's default tone mapping



Common Matlab-HDR



Proposed w/ weighted averaging



Magnifications (colors match colors left)

Side-by-side: left: common, right: proposed

Summary

- Simple HDR image generation
- Intermediate read-outs (samplings) *without* reset
- Pel-wise extrapolation
- Reduced image noise for low-light scenarios
- Improved detail preservation
- Reduced total image-aquisition time ⇒ reduced ghosting

No or small hardware changes ⇒ applicable for low-cost sensors (e. g. in smartphones)

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