High Dynamic Range Images from Digital Cameras Raw Data

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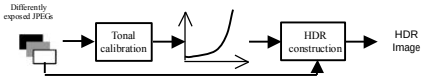
Tonal reproduction

Tonal reproduction of High Dynamic Range scene: achieved through multiple exposure image capture

Traditional approach: Using digital cameras pre-processed outputs



A few advantages:

- In-camera processes have already performed RAW decoding, demosaicing, and white and black point settings
- Noise reduction may have been applied

Many issues:

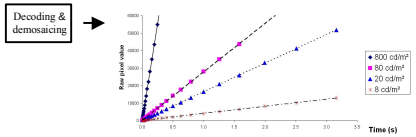
- In-camera processes apply non-linear curve to sensor data
  ⇨ Calibration calculation required to recover the curve applied (in order to undo it)
- Curve applied usually depends on characteristics of scene captured.
  ⇨ Calibration will be necessary for every new set of images
- So called "response curve" is a firmware process, not a camera characteristic (as in the case of films)
  ⇨ In-camera processes should not be confused with the concept of camera response curve. For a digital camera, the "real" camera response is the one of the sensors (available in the form of RAW data)
- Nothing guarantees that in-camera processes apply the same curve across the exposure range
  ⇨ Invalidates assumptions used by tonal calibration algorithms

Conclusion: In most cases, tonal calibration of differently exposed pre-processed outputs of digital cameras is not a reliable process and may lead to inaccurate recovery of the captured tonal values

Our approach: Using RAW data captured by sensors

Checking linearity of RAW data

1. Capture of HDR scene:
   - 36 exposures spaced by 1/3 EV
   - Canon 1D MKII camera in RAW mode
2. Determination approximate level of luminance for four positions in the scene: from about 8 to about 800 cd/m2
3. Plotting RAW data pixel values relative to exposure time for each one of the four luminance levels



- RAW pixel values can be considered linear across the whole range of exposures for medium luminance levels
- Non-linearity in neighborhood of saturation and noise levels is not an issue for the purpose of HDR image construction: weighting function ensures optimally exposed images are used

Conclusion: Linearity of sensor response across a large range of exposures makes tonal calibration unnecessary

Working directly with RAW data eliminates the calibration step, ensuring a more consistent tonal reproduction of HDR scenes

Color reproduction

Color reproduction of High Dynamic Range scene: a neglected topic in most algorithms

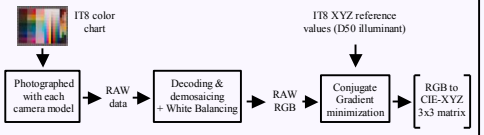
Algorithms for constructing HDR image focus on tonal rather than color reproduction (after all, the term "Dynamic Range" refers to tonal range).

The issues with color reproduction from pre-processed images:

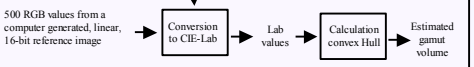
- Pre-processed images produced by digital cameras are Output-Referred. In-camera processes perform color rendering in such a way that it produces a pleasing image when looked on a display or print
  ⇨ High Dynamic Range Images are meant to be Scene-Referred rather than Output-Referred. HDRIs should reproduce the scene colorimetry as accurately as possible rather than being optimized for display on low dynamic range monitors with limited gamut
- One of the reasons for color rendering to Output-Referred color space is encoding efficiency. By selecting limited gamut color encoding such as sRGB or Adobe RGB, there is no waste on colors that are out of the display device gamut.
  ⇨ High Dynamic Range Image formats do not impose encoding limitation that justifies rendering to "economical" output space
- Reversing color rendering to Output-Referred color space can not be achieved by profiling the pre-processed outputs of digital cameras
  ⇨ Characterization should be done on RAW data instead, i.e. before color rendering to Output-Referred color space

Comparison of gamut volumes achievable:
Using RAW data vs Using Output-Referred color space

1) Sensor characterization of three camera models



2) Gamut volume estimation

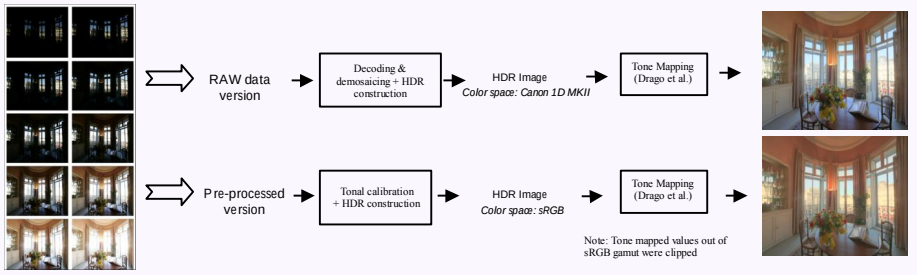


3) Results

	Volume	Ratio to sRGB
sRGB	560,958	1:1
Adobe RGB	804,354	1.43:1
Canon D30	1,196,562	2.13:1
Canon 1D Mark II	1,406,893	2.51:1
Fuji S3 Pro	1,428,578	2.55:1

Scene-Referred High Dynamic Range images require color reproduction from RAW data

Consequence for Tone Mapping algorithms:
Need to handle extended gamut available in HDR images generated from RAW data



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