Color correction for tone mapping

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Abstract

- Tone mapping algorithms
  - Offer sophisticated methods for mapping HDR to LDR
  - Changes in color appearance
- Measurement of change after tone mapping
  - Indication of relation between contrast compression and color saturation correction
- Proposal of color correction formulas
  - Available existing tone mapping algorithms

Introduction

- ◆ Tone mapping algorithms
  - – Often cause changes in color appearance
  - – Luminance compression
    - Darker tones to appear brighter
    - Distort contrast relationships

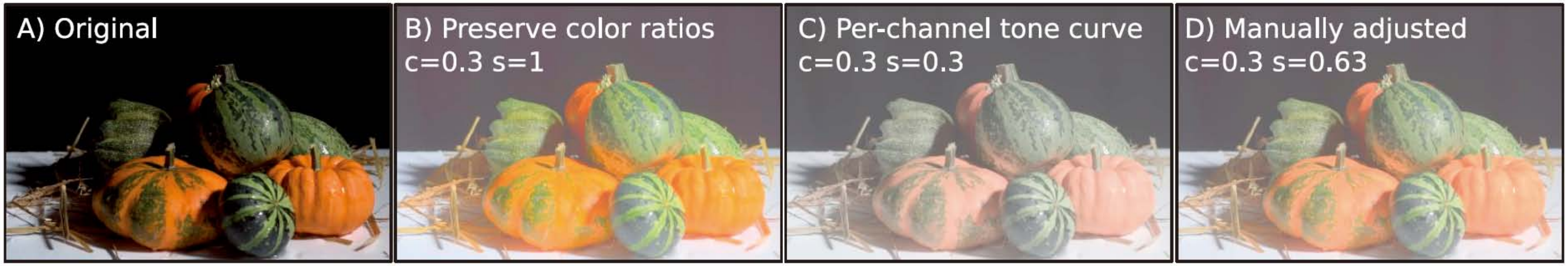


Fig. 1. An original image compared with three images after contrast compression.

- Object of this work
  - Quantify and model correction in color saturation
  - Distrust predictions of existing appearance models
    - Instead conduct subjective appearance matching
      - Measure necessary color correction
  - Find new chrominance values
    - Tone mapped image closely matches appearance of image with no tone modification

Related work

- Color reproduction
  - Well studied in context of gamut mapping
  - Gamut mapping
    - Modify both luminance and chrominance to preserve color appearance
    - Much smaller contrast compression than tone mapping
    - Operate on display-referred images
  - Proposed method
    - Only modify chrominance
      - Tone mapping modify luminance
    - Operate on scene-referred images

◆ Color appearance studies

- Apparent colorfulness of uniform color patches
  - Vary with luminance, image size, and color of surround
  - Hunt effect
- Apparent lightness of color patches
  - Depend on chromacity
  - Helmholtz & Kohlrausch effect
- Apparent hue
  - Depend on luminance
  - Abney effect
- Perceived contrast of images
  - Decrease with reduced chroma
  - Sigmoidal relation

- Color reproduction in tone mapping
  - Focus on preserving color appearance of real-world scene
  - Pattanaik et al.
    - Introduce complex model of human color vision
    - Introduce opponent color processing
    - Gain control for both luminance and contrast signals
  - Later work
    - Focus on aspects of temporal adaptation
      - Use photoreceptor model instead of luminance gain control
    - Employ simplified appearance model based on Hunt's model

◆ Color appearance model

- iCAM color appearance model
  - Achieve contrast compression
    - Applying spatially varying power function to three color channels in LMS color space
- iCAM06 color appearance model
  - Replace power function with photoreceptor response model
  - Consider separately scotopic and photopic signals
  - Account for perceived contrast change with adapting luminance level and with surround luminance
  - Compensate for increased colorfulness with luminance

- Akyuz and Reinhard
  - Propose color processing framework
    - Adapt to any tone mapping that preserves ratios between color channels
  - Use forward and then backward CIECAM02 model
- Mentioned tone mapping operators
  - Account for color differences
    - Result of different luminance and chromatic adaptation between real-world scene and display viewing conditions
  - No considered change in color appearance

Color correction in tone mapping

◆ Common approach to color treatment

– Preserving color ratios

$$C_{out} = \frac{C_{in}}{L_{in}} L_{out} \tag{1}$$

where C is one of RGB color channels,
L is pixel luminance, and
in/out is pixels before and after tone mapping.

- Stronger contrast compression in tone mapping
  - Over-saturated result image

◆ Ad-hoc formula

$$C_{out} = \left(\frac{C_{in}}{L_{in}}\right)^{s} L_{out} \tag{2}$$

where s is color saturation control factor.

– Drawback of equation

- Change resulting luminance for $S \neq 1$ and for colors different from gray

$$k_R R_{out} + k_G G_{out} + k_B B_{out} \neq L_{out}$$

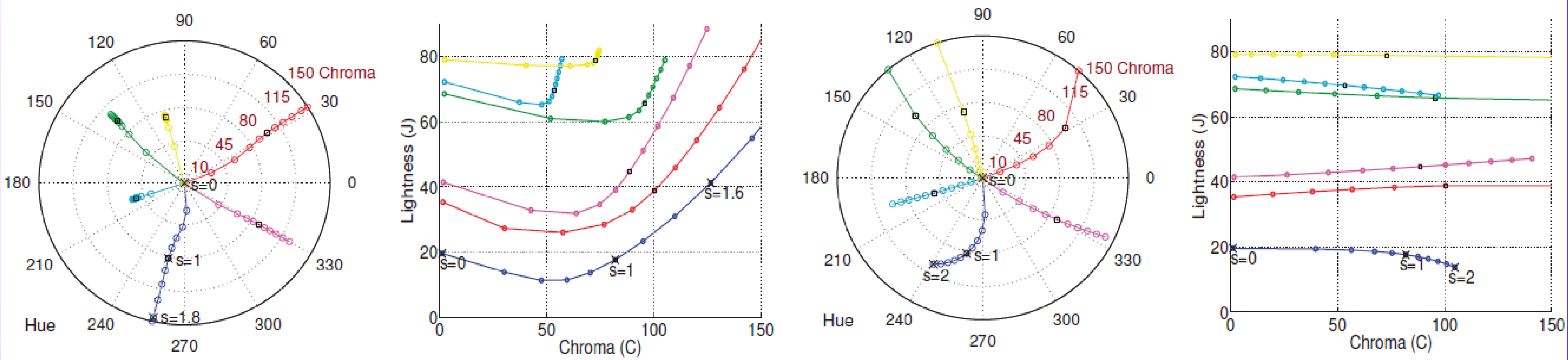
where $k_{R,G,B}$ are linear factors to compute luminance for given color space.

◆ Introduction of another color correction

$$C_{out} = \left(\left(\frac{C_{in}}{L_{in}} - 1 \right) s + 1 \right) L_{out} \tag{3}$$

– Difference between equation 2 and 3

- Change in S from Equation 2
  – Modification both chroma and lightness of colors
- Change in S from Equation 3
  – Prevent lightness, but lead to stronger hue shift



(a) Equation 2 (b) Equation 3

Fig. 2. CIECAM02 prediction of hue, chroma, and lightness
for the non-linear (a) and luminance preserving (b) color correction formulas.

Fig.7

- Another approach to color treatment
  - Apply same tone mapping curve to all color channels
    - Form of tone curve

$$L_{out} = \left(L_{in} b\right)^{c} \tag{4}$$

where b is brightness adjustment that normalizes for maximum display brightness.

    - Another arbitrary tone-curve
      - Apply color correction factor s of Equation 2
        - Not equivalent to $s = c$
        - Results are very close
    - In case of local tone mapping operators
      - All channels usually cannot be modified simultaneously
      - Rely on color transfer formulas, such as Eq. 2 or 3

- Equations 2 and 3
  - Convenient way of correcting colors in RGB
  - Manual adjustment of parameter s
- Object
  - Estimation of color correction parameter s given luminance-specific tone-curve

Experiment 1: color matching for tone mapping

- Practice of subjective study
  - How much color correction is required to compensate for contrast compression?
- Participants of experiment
  - Split into two parts to test
    - Test group for non-linear Equation 2
    - Test group for luminance preserving Equation 3

◆ Stimuli

– 8 natural images in experiment


HDR: Pile of gourds

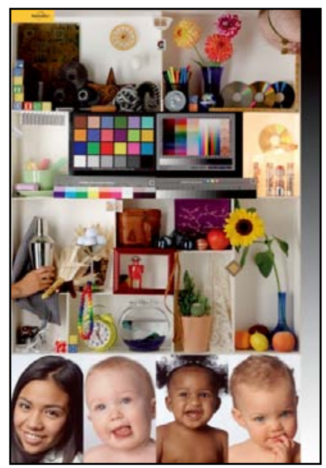

HDR: Ouchy


LDR: Violet


LDR: Grey, Gray and Blue


HDR: Memorial


HDR: Portrait


LDR: PDI


LDR: Half a face is better than a whole one

Fig. 3. HDR and LDR images used in the experiments.

- Image processing
  - Use Eq. 4 for contrast compression
    - Contrast factor c varied from 0.1 to 1.6
  - Use Eq. 2 and 3 for Color correction
    - Color saturation factor s were adjusted by participant
- Reduce luminance of input image
  - Use 33% of display peak luminance
  - Avoid out-of-gamut

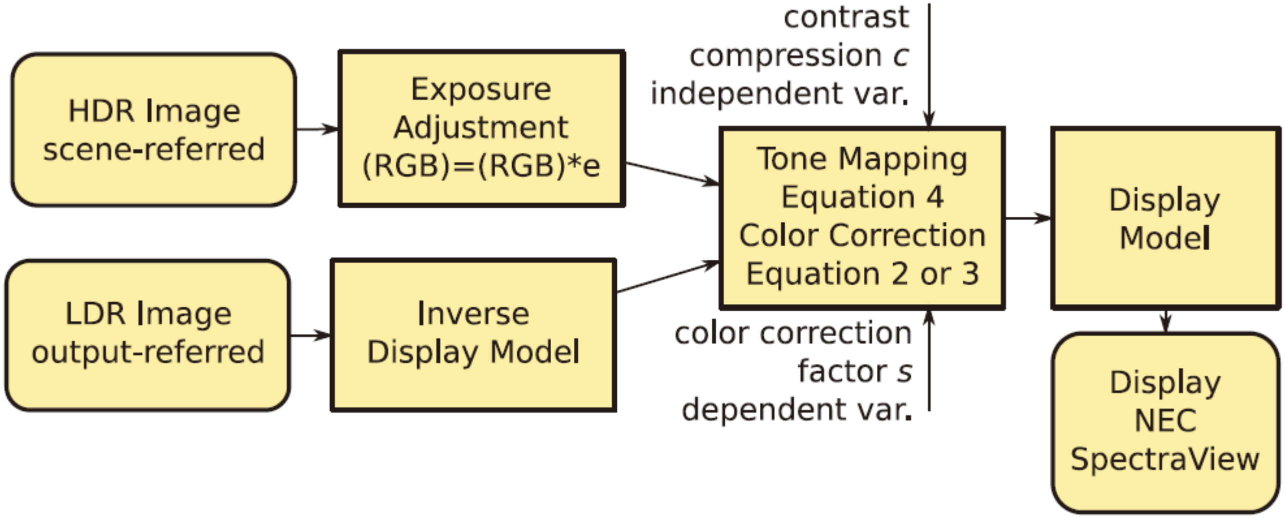


Fig. 4. Tone mapping and color correction used in the experiments.

◆ Experimental procedure

- Change color correction factor s by participants
- Matching colorfulness
  - Average of both left and right image

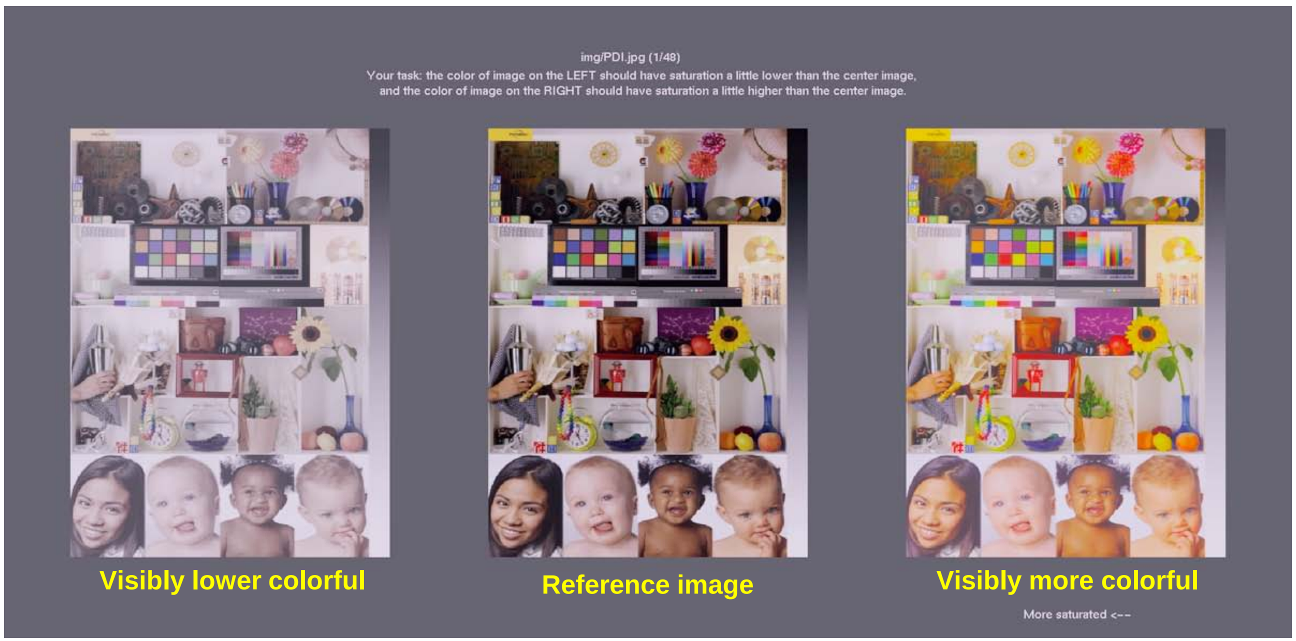
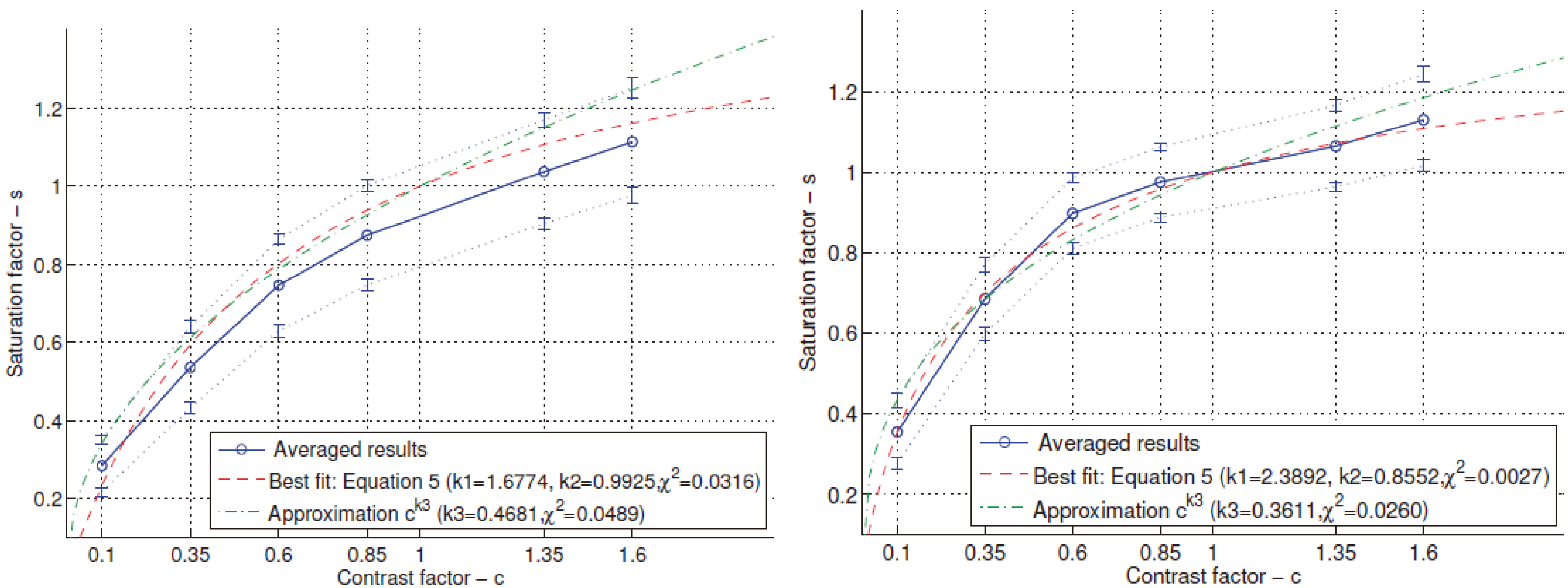


Fig. 6. Screenshot from the experiment.

◆ Results

- Averaged results for both color correction formulas
  - Moderate contrast correction for small contrast
- Relation between c and s
  - Approximate with power function $s(c) = c^{k_3}$
  - Approximate with $s(c) = \dfrac{(1+k_1)c^{k_2}}{1+k_1 c^{k_2}}$ (5)



(a) Non-linear color correction (b) Luminance preserving correction

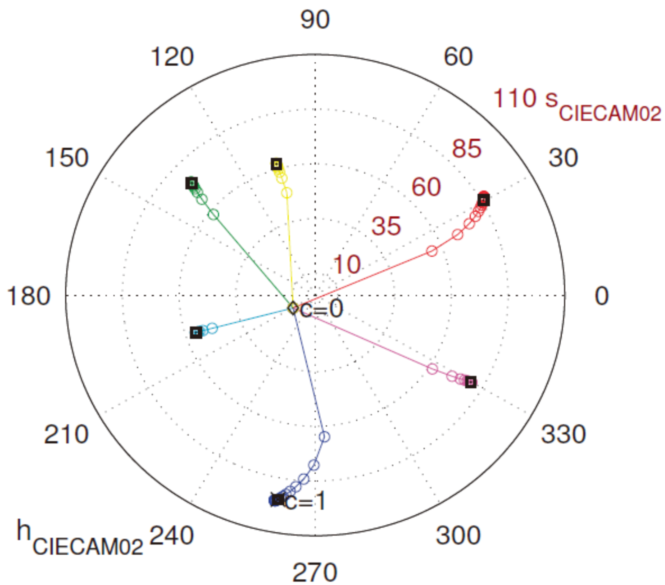
Fig. 5. Result of matching colors between image with altered contrast and an original image.

Color appearance models and color correction

- Color appearance models
  - Predict non-linearity in visual system
  - Provide set of perceptual attribute predictors
    - Colorfulness, chroma, and saturation
- Object of this experiment
  - Find which perceptual attribute should be preserved after contrast compression
    - Six basic colors of different hue, saturation, and lightness
      - Compress contrast $c \in [0, 2]$ with respect to reference white
      - Color correction factor s determined by Eq. 5
    - Result colors
      - Transform to space of perceptual attribute predictors

– Result colors of CIECAM02 space

- CIECAM02 saturation
  - Most consistent across contrast variation
- Relation between the saturation and contrast compression
  - Non-linear relation



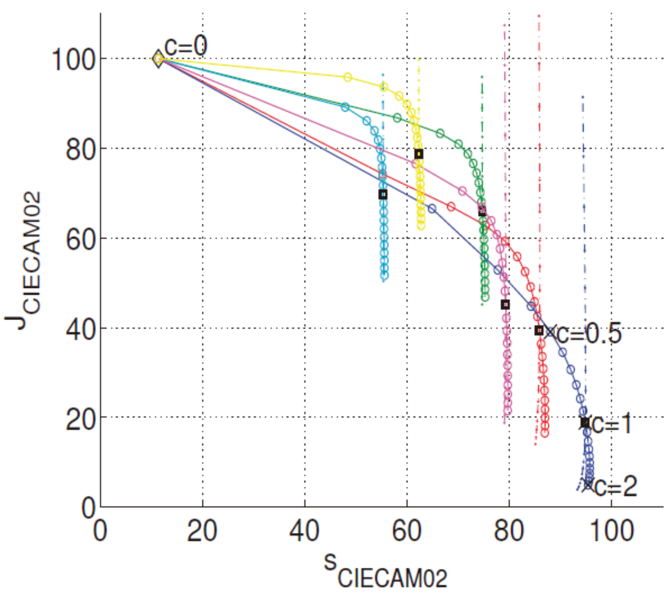


Fig. 7. CIECAM02 prediction (hue, saturation, and lightness) for color change.

Fig.2

Experiment 2: Color correction in CIELAB

- Limitations of color correction in RGB space
  - Either preserve lightness but distort hue, or preserve hue but distort lightness
- Color correction in space of perceptual attributes
  - CIELAB or CIELUV color space
  - Simpler color correction
  - Resulting images
    - Better match to originals

◆ Framework for color correction in CIELAB

- Luminance of original image
  - Tone mapping by Eq. (4)
- Chroma of original image
  - Correct by factor s_{LAB}
- Combine lightness and corrected chroma

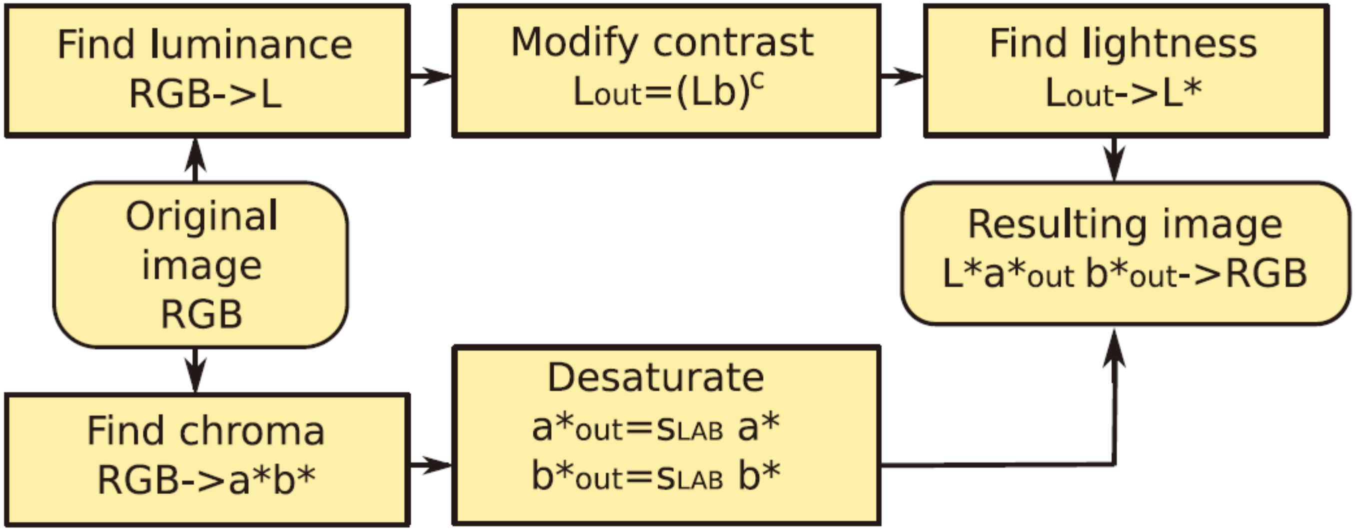


Fig. 8. Colors correction in the CIELAB color space.

◆ Result of experiment

– Small contrast modification ($0.6 < c < 1.6$)

- Color correction
  – Almost unnecessary ($s_{LAB} \approx 1$)

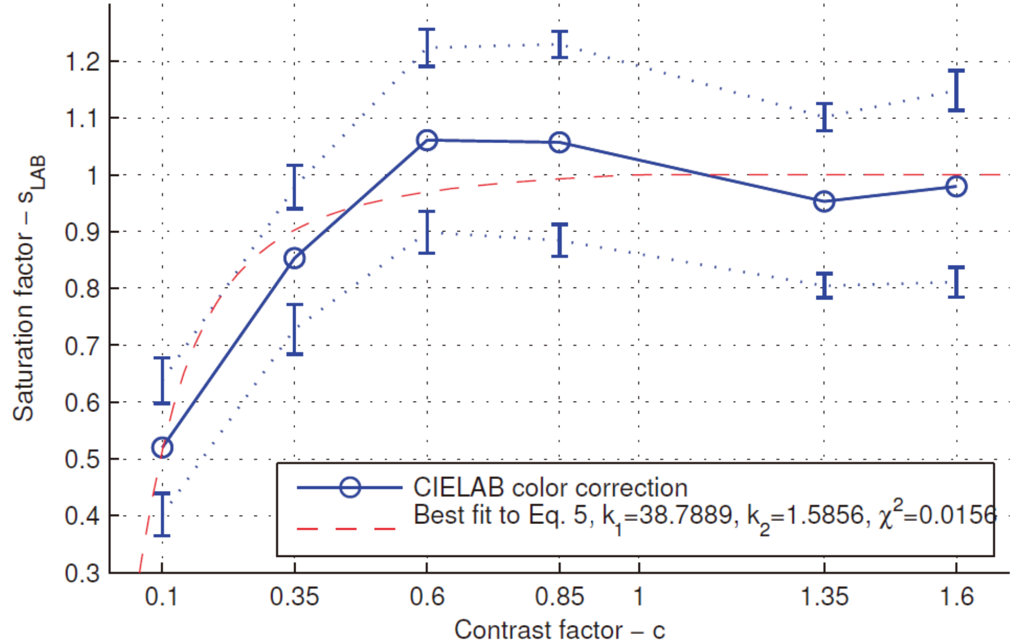


Fig. 9. Result of matching image colors using color correction in CIELAB color space.

– Illustration of s_{LAB} color correction in CIECAM02

- Color correction in CIELAB
  - Better preserve hue and lightness

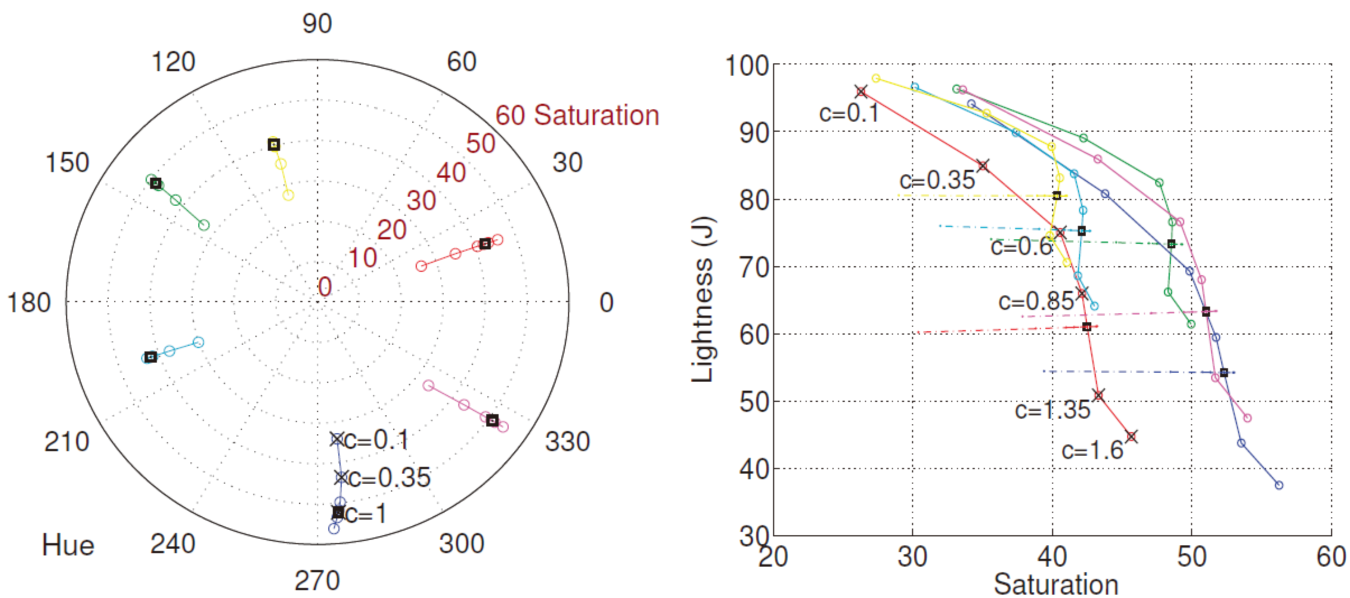


Fig. 10. CIECAM02 prediction for color correction in CIELAB space.

Are color appearance models suitable for tone mapping?

- CIELAB chroma predictor
  - Better preserve color appearance after contrast compression
    - Seem to be alternative to color correction in RGB color space
  - Limitation for HDR scenes
    - Estimation problem of reference white color

◆ Different selection of reference white

- Lead to completely different colors
- Automatic estimation of reference white
  - Difficult problem
  - Some methods exist
    - Lead to unreliable estimation

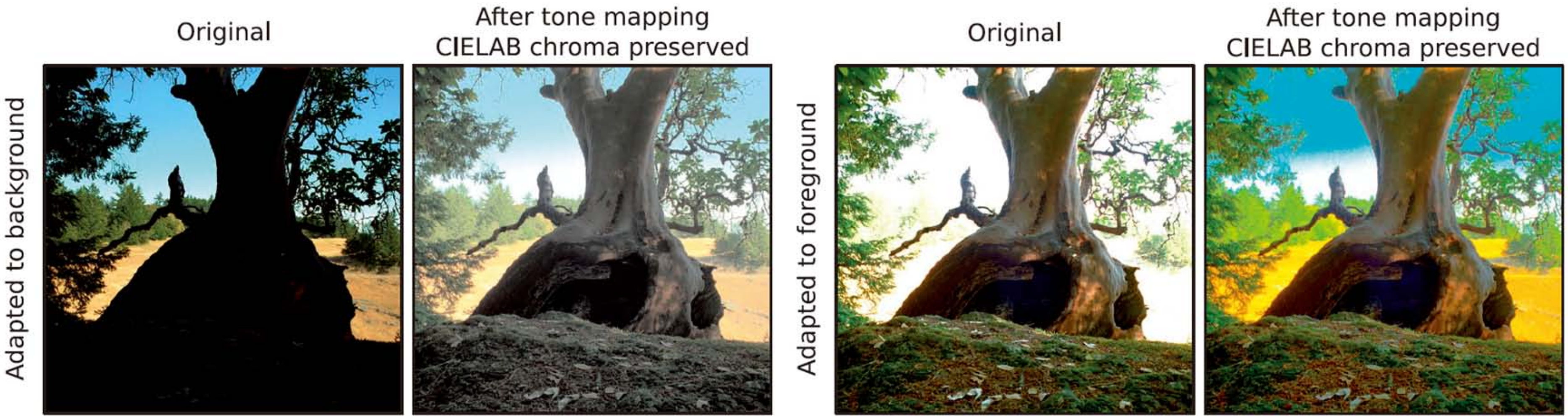


Fig. 11. High dynamic range image before and after tone mapping while preserving CIELAB chroma.

Application in tone mapping

- This subjective study
  - Demonstrate relation between contrast compression and color correction
  - Applicable to global and local tone mapping

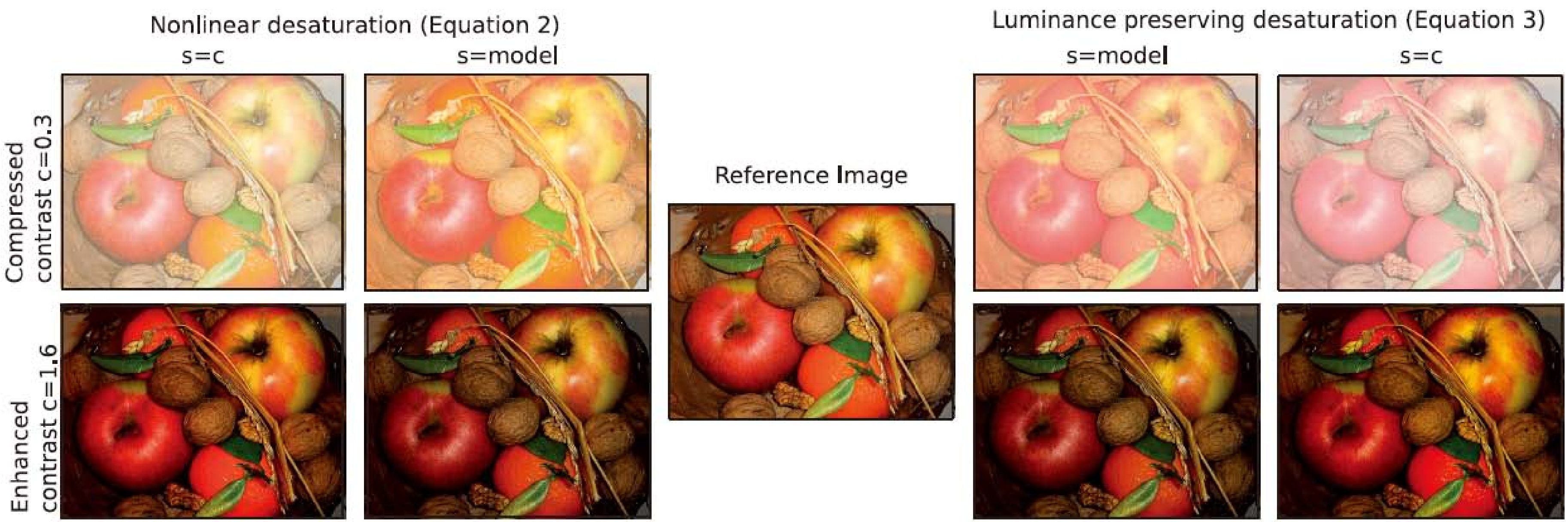


Fig. 12. Results of four color correction methods for contrast compression(top) and enhancement(bottom).

◆ Bilateral tone mapping

- Uniformly reduce contrast of base layer while detail preserving
- Produce good result, but over-saturated colors
- Using proposed method
  - Fix over-saturated colors

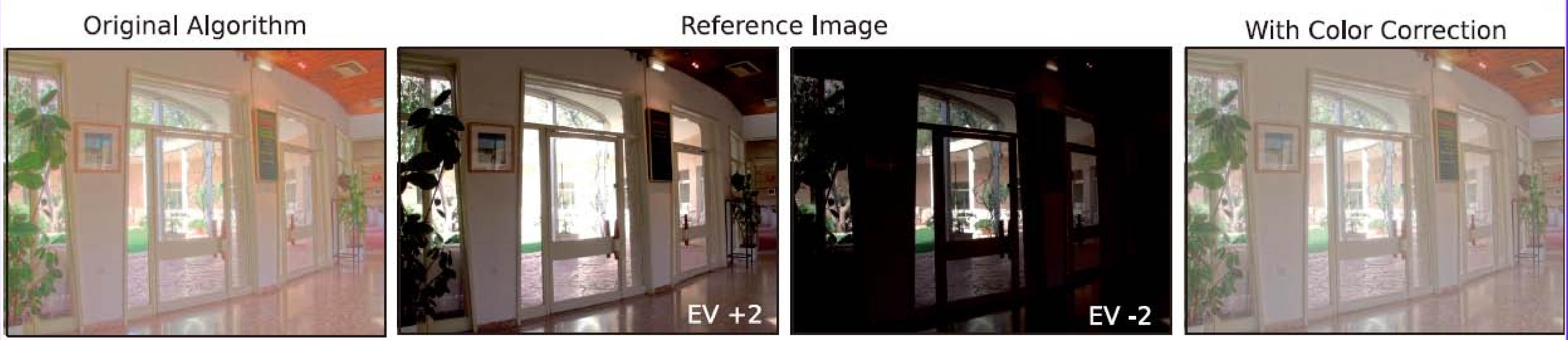


Fig. 13. The result of the “bilateral” tone mapping with strong contrast compression, original algorithm compared to the algorithm with color correction.

◆ Proposed color correction formulas

- Apply to simplified operator with contrast factor c
- Apply to any tone mapping function
  - Contrast factor
    - Approximate by slope of tone curve on log-log plot in logarithmic space

$$\hat{\hat{\hat{L}}}_{out} := tmo\left(L_{in}\right)$$
$$c\left(L_{in}\right) = \tfrac{d}{d\hat{L}} tmo\left(\hat{L}_{in}\right) \qquad (6)$$

where $\hat{L} = \log_{10}\left(L\right)$

◆ Display adaptive tone mapping

- Employ Eq.(2) to compensate for color difference
  - Manually adjust color correction factor s

$$C_{out} = \left(\frac{C_{in}}{L_{in}}\right)^{s} L_{out}$$

- Using proposed method
  - Automatically readjust s

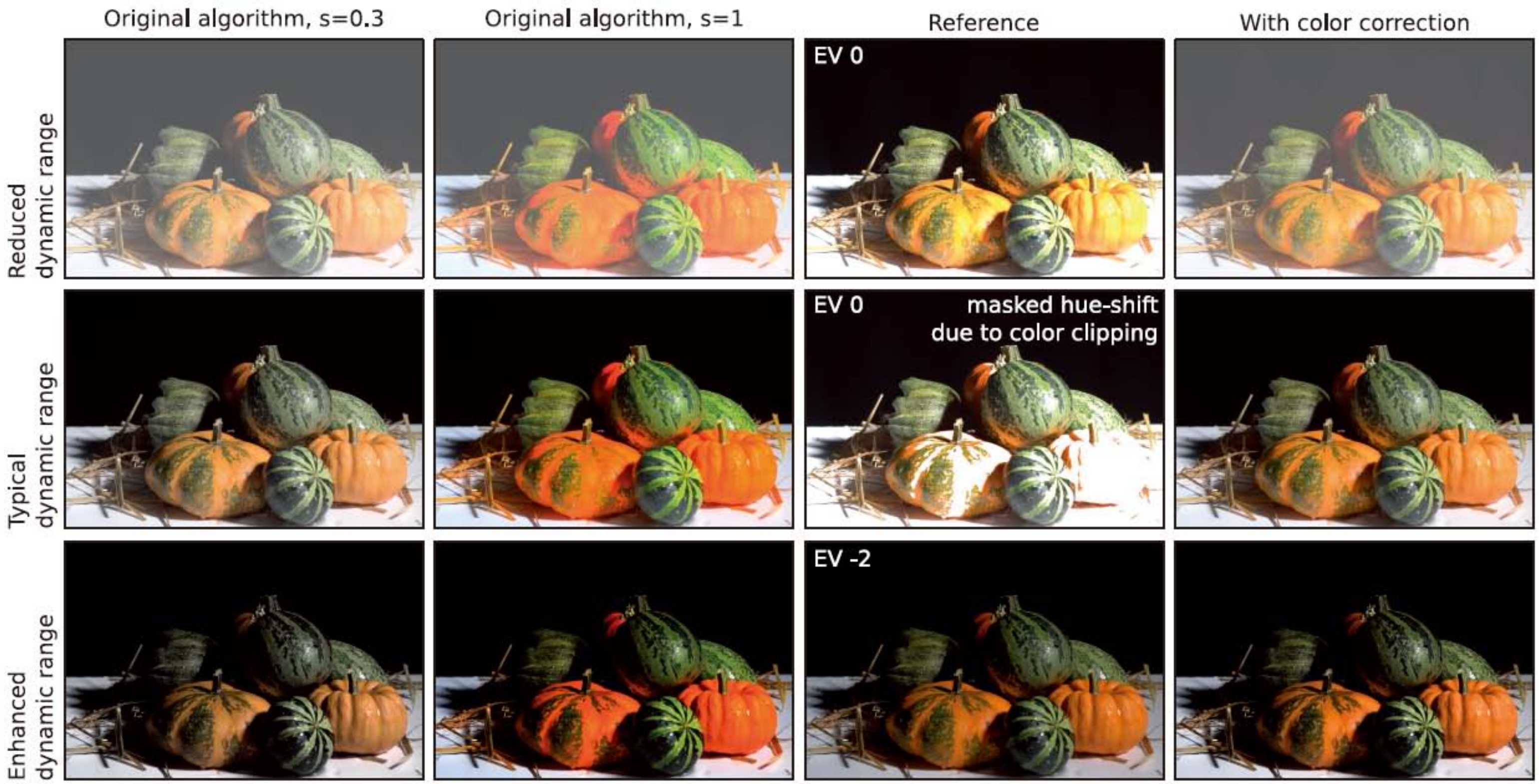


Fig. 14. The result of the “display adaptive” tone mapping.

Discussion

◆ Proposed method

– Consideration of only global tone mapping

- Affect only low frequencies

– Pilot study

- Investigate effect of local operation, unsharp masking, and colorfulness images
- Main component of local tone mapping operators
  - Sharpening
  - Proposed color correction
    - » Valid method for local tone mapping operators

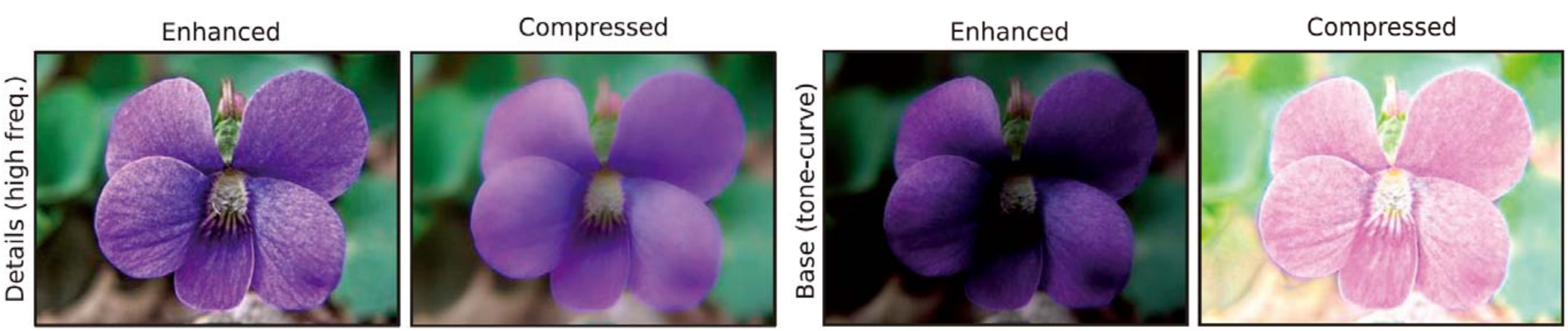


Fig. 15. Enhancement and compression of details has little effect on colorfulness as compared to global contrast modification.

Conclusions and future work

- Tone mapping operator
  - Distort image due to tone and color reproduction
- Proposal method
  - Predict desirable color correction
  - Simple and computationally inexpensive formulas
  - Applicable for global and local tone mapping
  - Exist problem of reference white estimation
- Future work
  - Isolate set of factors that influence colorfulness after local tone mapping operations