Tone-mapping High Dynamic Range Images by Novel Histogram Adjustment

Pattern Recognition

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Jiang Duan, Marco Bressan, Chris Dance, and Guoping Qiu

Presented by Il-Su Park

School of Electrical Engineering and Computer Science
Kyungpook National Univ.

Abstract

- Proposed method
  - Novel histogram adjustment method
    - Global histogram adjustment
      - Reproduction of global contrast for high dynamic range image
    - Segmentation of image
    - Performance of adaptive contrast adjustment
      - Use of global tone mapping operator in local region
        - » Reproduction of local contrast
        - » Guarantee of better quality

Introduction

- High dynamic range(HDR)
  - Dynamic range
    - Ratio of the highest to the lowest luminance or signal level
  - Real world dynamic range
    - Approximately fourteen orders of magnitude
  - Performance of digital image capture and display devices
    - Match or even exceed performance of film
      - Accuracy
      - Resolution
    - Sufferance of limited dynamic range

– Tone mapping(tone reproduction)

- Reproduction of HDR radiance map on LDR device

Fig. 1. Tone mapping example by our local operator described in this paper. Left small images are the selected multi-exposed image set of the original scene. Right image is a tone mapped result of the HDR radiance map constructed using left multi-exposed image set. Images courtesy of Fattal et al., The Hebrew University of Jerusalem.

Review of tone mapping methods

- Tone reproduction techniques
  - Global tone mapping operators
    - Simple
    - Preservation of intensity orders of original scenes
      - Avoiding halo artifacts
  - Previous global tone mapping operators
    - Tumblin and Rushmeier
      - Match perceived brightness of displayed image with brightness of scene
    - Ward
      - Match perceived contrast between displayed image and scene

- Ferwerda et al.
  - Computational model of visual adaptation
- Larson et al.
  - Histogram adjustment technique
    - » Population of local adaptation luminance in scene.
- Drago et al.
  - Adaptive logarithmic mapping strategy
    - » Change to base of logarithm function based on luminance level
- Duan et al.
  - Novel global tone mapping operator
    - » Visualizing a series of tone mapped versions

- Local tone mapping operators
  - Preservation of details and local contrast
  - Consider pixel neighborhood information in mapping processing for each individual pixel
- Previous local tone mapping operators
  - Tumblin and Turk
    - Layer-based method
      - » Extension of anisotropic diffusion
      - » Edges-preserving low-pass filter
  - Durand and Dorsey
    - Simpler layer-based method
      - » Using base layer and detail layer
    - Obtaining base layer
      - » Use of bilateral filter

- Li et al.
  - Bilateral filtering method
    - » Adjustment to base layer
      - » Using global mapping function
    - » Enhancement of detail layer
      - » Using gain map obtained in base layer
- Li et al.
  - Multiscale image processing technique
    - » Use of symmetrical analysis–synthesis filter bank
    - » Computation of smooth gain map for multiscale subband image
- Reinhard et al.
  - Novel local approach
    - » Well-known photographic practice of dodging-and-burning

- Fattal et al.
  - Manipulation of gradient domain in logarithmic space
    - » Calculation of gradient in logarithmic luminance domain
    - » Detection of contrast magnitude in corresponding position in original luminance domain
- Krawczyk et al.
  - Segmentation of HDR image
    - » Anchoring theory of lightness perception
  - Local calculation of lightness values
  - Merging frameworks proportional to strength
- Lischinski et al.
  - Novel interactive local adjustment method
    - » Tonal values and other visual parameters

– Proposed method

- Novel fast global histogram adjustment
  - Utilization of full dynamic range of display
  - Reproduction of global contrast
  - Insufficient preservation of local contrast and details
- Novel local tone mapping operator
  - Extension of global tone mapping operator to local tone mapping operator
    - » Segmentation of image
    - » Performance of adaptive contrast adjustment
      - » Using developed global tone mapping operator
  - Sharp jumps among different block
- Novel bilateral weighting scheme
  - Elimination of boundary artifact and halo artifact

Global tone mapping operator

- Logarithm function to luminance
  - Increase of contrast and brightness
    - Low luminance value
  - Compression of contrast and brightness
    - High luminance value

$$D(I) = \left(D_{\max} - D_{\min}\right) * \frac{\log\left(I+\tau\right) - \log\left(I_{\min}+\tau\right)}{\log\left(I_{\max}+\tau\right) - \log\left(I_{\min}+\tau\right)} + D_{\min} \qquad (1)$$

where $I_{\min}$ and $I_{\max}$ are the minimum and maximum luminance of the scene,
$D_{\max}$ and $D_{\max}$ are the maximum and minimum display levels of the visualization devices, and
τ controls the overall brightness of the mapped image.

– Result of different values of τ

Fig. 2. A high dynamic range image mapped using Eq. (1) with different values of τ. The offset of the image on the right bottom is computed automatically. Radiance map courtesy of Paul Debevec.

– Estimate of parameter τ

- Log-average luminance of scene
  - Mapping specific point in display dynamic range depending on scene brightness
- Procedure
  - Calculate log-average luminance I_{ave} of scene

$$I_{\mathrm{ave}} = \exp\left[\frac{1}{N}\sum_{x,y}\log\left(\varepsilon + I(x,y)\right)\right] \tag{2}$$

where N is the total pixel number in the image,
$I(x,y)$ is the luminance value whose minimal can be 0 for pure black point, and
a small value ε is used to avoid the singularity that occurs with 0 values in these cases when taking logarithm operation.

– Calculate key value of image on scale between 0 and 1

$$k = A \times B^{\left(2\log I_{\text{ave}} - \log I_{\text{min}} - \log I_{\text{max}}\right)/\left(\log I_{\text{max}} - \log I_{\text{min}}\right)} \qquad (3)$$

where constants A and B are empirically set to 0.4 and 2, and thus k range form 0.2 to 0.8.

– Decide offset τ

» Use of numerical calculation

$$k = \frac{\log\left(I_{\text{ave}} + \tau\right) - \log\left(I_{\text{min}} + \tau\right)}{\log\left(I_{\text{max}} + \tau\right) - \log\left(I_{\text{min}} + \tau\right)} \qquad (4)$$

– Division of range of D(I)

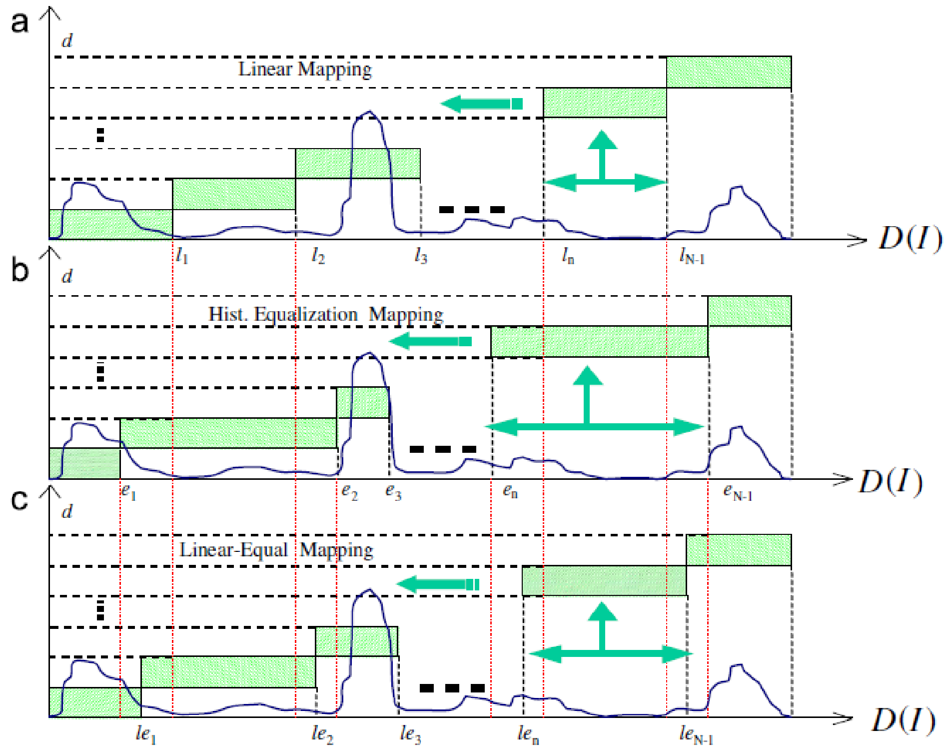


Fig. 3. Mapping the output of Eq. (1) for display. (a) Linear mapping divides compact luminance range [Dmin, Dmax] into N=256 equal length intervals and maps pixels falling into the same interval to the same integer display level d. (b) Histogram equalized mapping divides [Dmin, Dmax] into N=256 intervals such that the number of pixels falling into each interval is the same. (c) The quantizer of our algorithm divides [Dmin, Dmax] into N=256 intervals in such a way that the cutting points

– Histogram adjustment based linear to equalized quantizer(HALEQ)

$$le_n = l_n + \beta\left(e_n - l_n\right) \qquad (5)$$

where $0 \le \beta \le 1$ is a controlling parameter.

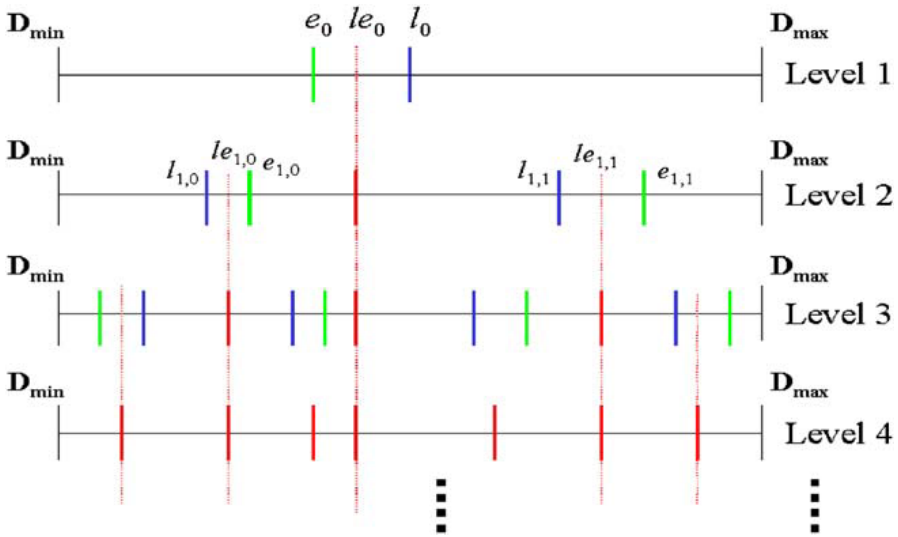
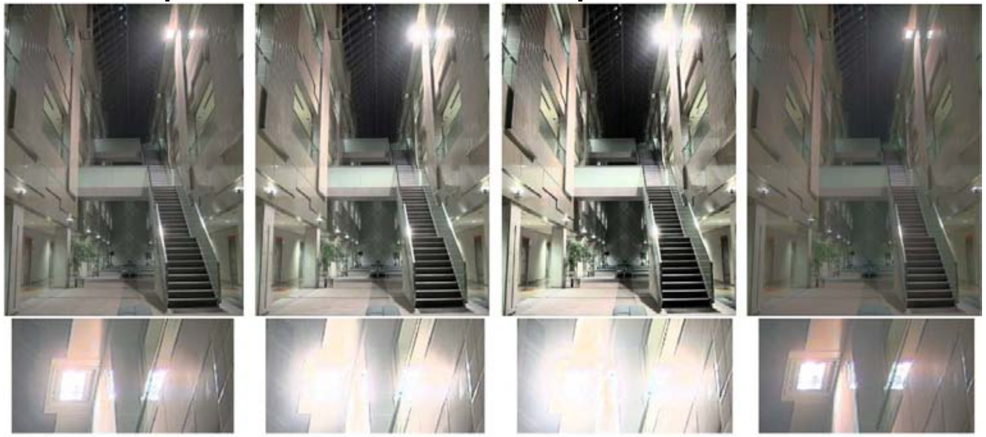


Fig. 4. Recursive binary cut approach implementation of HALEQ. The algorithm first divides the range of D(I) into two segments according to Eq. (5). Then these two segments are each independently divided into 2 segments according to Eq. (5). The process is then applied recursively onto each resultant segment to divide it into 2 new segments based on Eq. (5) until the predefined number of segments (256) are created.

– Mapping results and mapping curves

- Existence of very few very bright pixels
  - Correspond to area of lamps



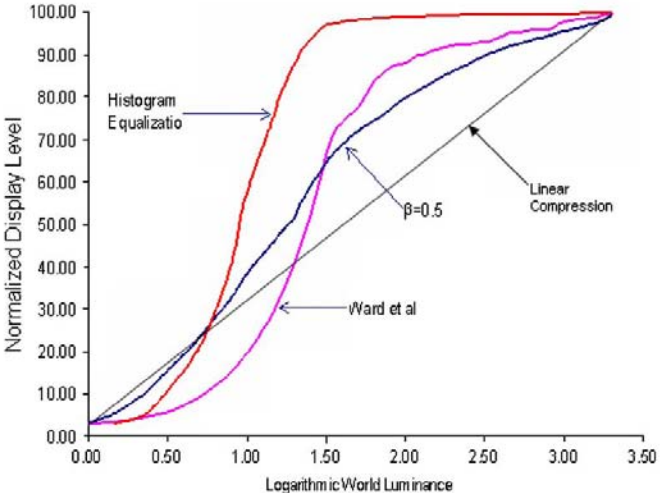


Fig. 5. Top row: left to right, AtriumNight images mapped by our new method HALEQ, the method of Larson et al. [8], histogram equalization and linear compression. Middle row: amplified regions of the images above them. Bottom row: tone mapping curves of these used methods for the image. Radiance map courtesy Karol Myszkowski.

Local tone mapping operator

- Adaptive local histogram adjustment(ALHA)
  - Characteristic of HALEQ
    - Effective utilization of dynamic range of display
  - Segment image into small regions
  - Applying HALEQ in each local area
    - Full display dynamic range

◆ HALEQ in local regions

- Logarithmic mapping (Eq.(1))
- Determination of local regions
  - Division of image into non-overlapping regular rectangular blocks

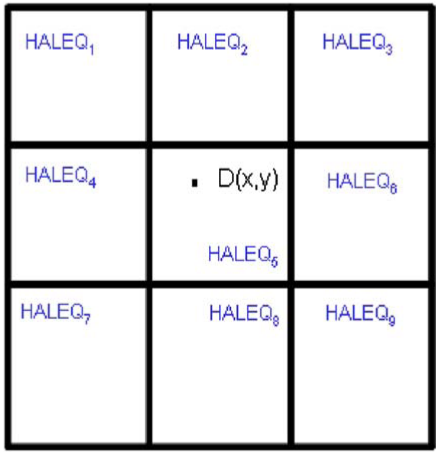


Fig. 6. Left: divide the image into blocks and then apply HALEQ technique developed in Section 3 to each individual block.

– Output integer display level $d(x,y)$

$$d(x,y) = \mathrm{HALEQ_n}\left[D(x,y)\right] \quad (x,y) \in n \tag{6}$$

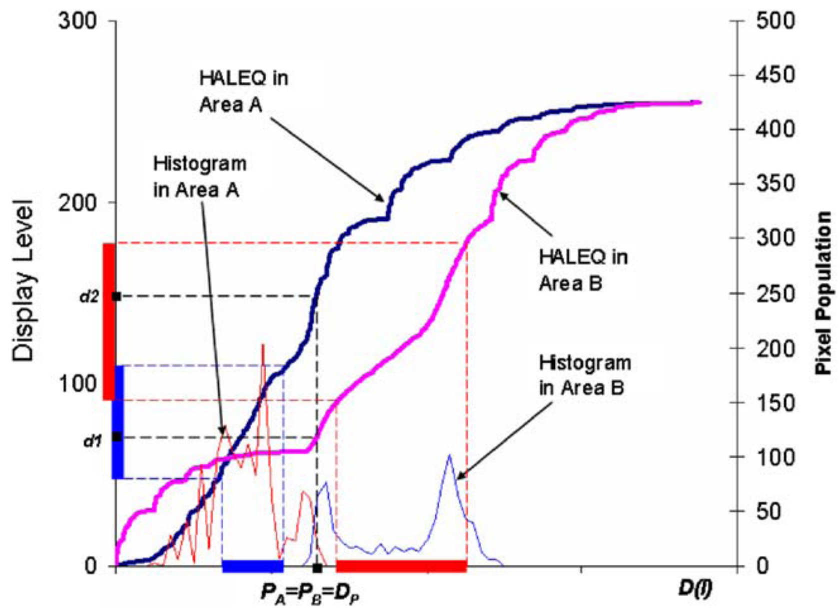


Fig. 7. The mapping functions and histograms for two different local areas A and B of an example image (The right image of Fig. 9).

– Normalized histograms of area A after applying different approaches to D(I)

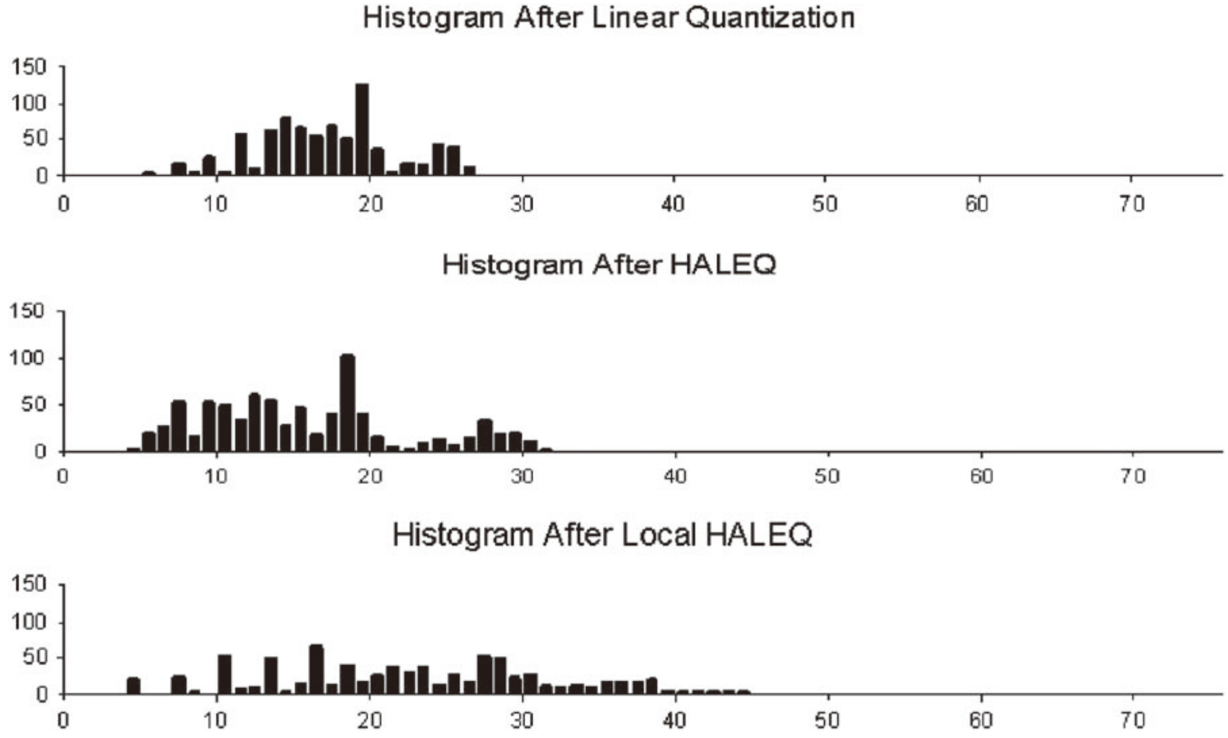


Fig. 8. Normalized histograms of area A after different approaches are applied to D(I) output by Eq. (1). Top: the histogram from the linear quantization. Middle: histogram from the original HALEQ. Bottom: histogram from local HALEQ.

– Mapping results from local HALEQ method

- More details and local contrast in either dark or bright regions
- Boundary artifacts

Fig. 9. Mapping results from local HALEQ. Memorial radiance map courtesy of Paul Debevec, University of California at Berkeley; Clock building radiance map courtesy of Greg Ward.

– Solution to boundary artifact

- Weighted average of results from tone mapping function

$$d(x,y) = \frac{\sum_{n=1}^{n=K} \mathrm{HALEQ_n}\left[D(x,y)\right] \cdot w_d(n)}{\sum_{n=1}^{n=K} w_d(n)} \tag{7}$$

where distance weighting function w_d is calculated as

$$w_d(n) = e^{-(d_n/\sigma_d)} \tag{8}$$

where d_n is the Euclidean distance between the current pixel position and the centers of each of the blocks,
σ_d controls the smoothness of the image.

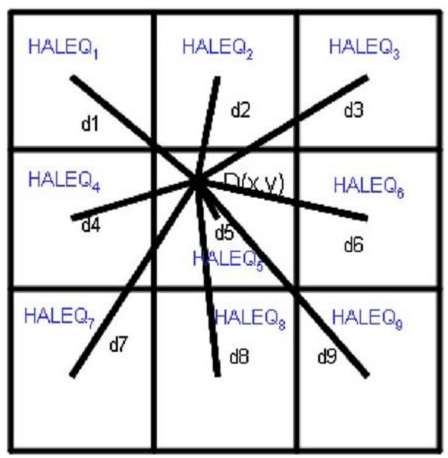


Fig. 6. Right: distance weighting function is introduced to eliminate the boundary artifacts. For easy illustration, only 9 blocks are used in this figure.

– Result Image after considering distance weighting function

- Removal of boundary artifacts

Fig. 10. Mapped results after the consideration of distance weighting function.

◆ Adaptive selection of parameter β in uniform areas

- Noise artifacts in relatively uniform areas
- Solution to noise artifacts
  - Decrease in degree of contrast enhancement in blocks with relatively uniform areas
    - Decreasing parameter β of HALEQ technique
- Detection of uniform areas
  - Characteristic of blocks with uniform areas
    - Narrow shaped histogram after logarithmic mapping
  - Uniformity measurement for each block n

$$SD_n = \frac{\sum_{i=0}^{i=M} \left| Hist(i) - mean_n \right|}{\text{Bin number}} \tag{9}$$

where M is the bin number,
Hist(i) is the pixel population in ith bin, and
the mean is the mean pixel population in each bin.

- Decision about uniform area

$$SD_n \geq \eta \quad (10)$$

where η is the threshold

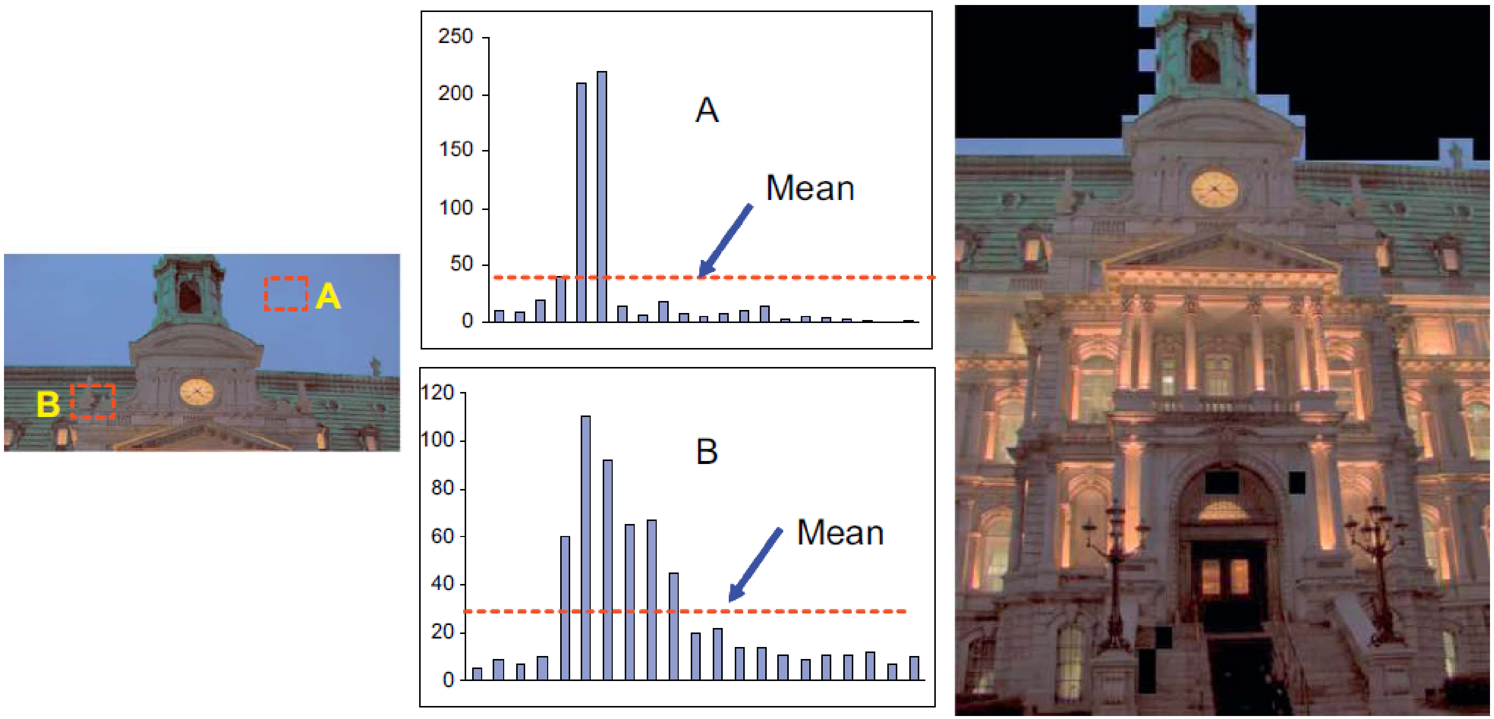


Fig. 11. Left and Middle: comparison of the histograms between uniform area and non-uniform area. Right: detected uniform areas in an example image.

– Decrease in parameter β in uniform areas

$$\beta = 0.6 * \left[1 - e^{-(20 - SD_n)}\right] \tag{11}$$

- Plot of β against SD_n according to Eq.(11)

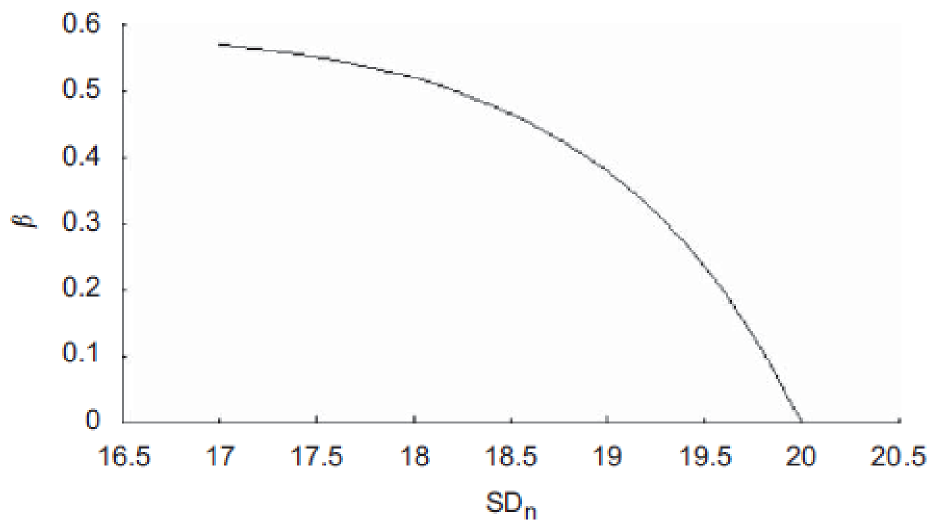


Fig. 12. The function used to smoothly decrease the parameter β depends on the degree of uniformity (standard deviation SDn) in corresponding blocks.

– Mapped image before and after consideration of uniform areas in image

  - More natural appearance in sky

Fig. 13. The mapped results before (left) and after (right) considering the uniform areas in the image. Halo artifacts are presented in some mapped images (The image on the right is an example of these images).

◆ Removing halo artifacts

– Halo artifact

- Occur contours of objects neighbor uniform areas

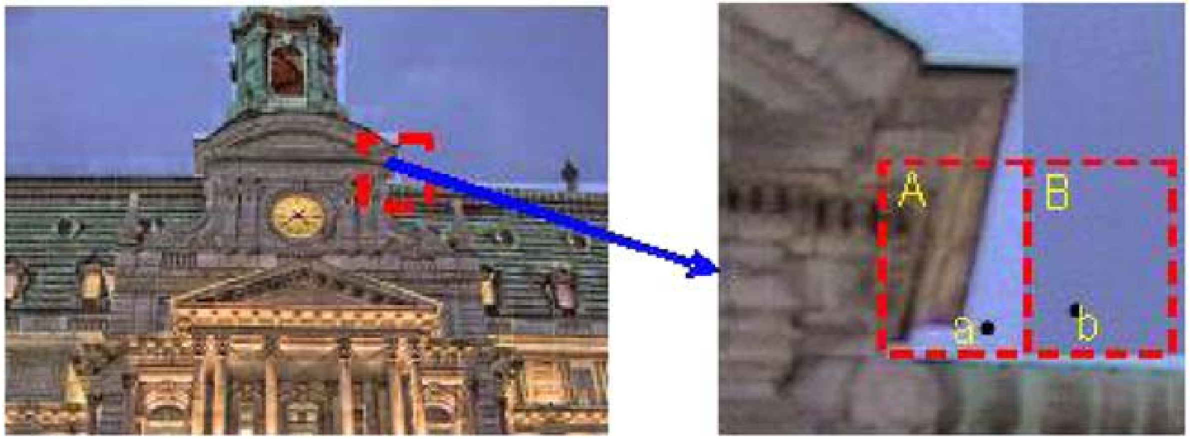


Fig. 14. The reason of causing halo artifacts at the contours of the objects that neighbor uniform areas.

– Solve halo artifact problem

- Bilateral weighting scheme
  - Add similarity weighting function to Eq. (8)

$$d(x,y)=\frac{\sum_{n=1}^{n=K}\mathrm{HALEQ}_{\mathrm{n}}\left[D(x,y)\right]\cdot w_d(n)\cdot w_s(n)}{\sum_{n=1}^{n=K}w_d(n)\cdot w_s(n)} \qquad (12)$$

where

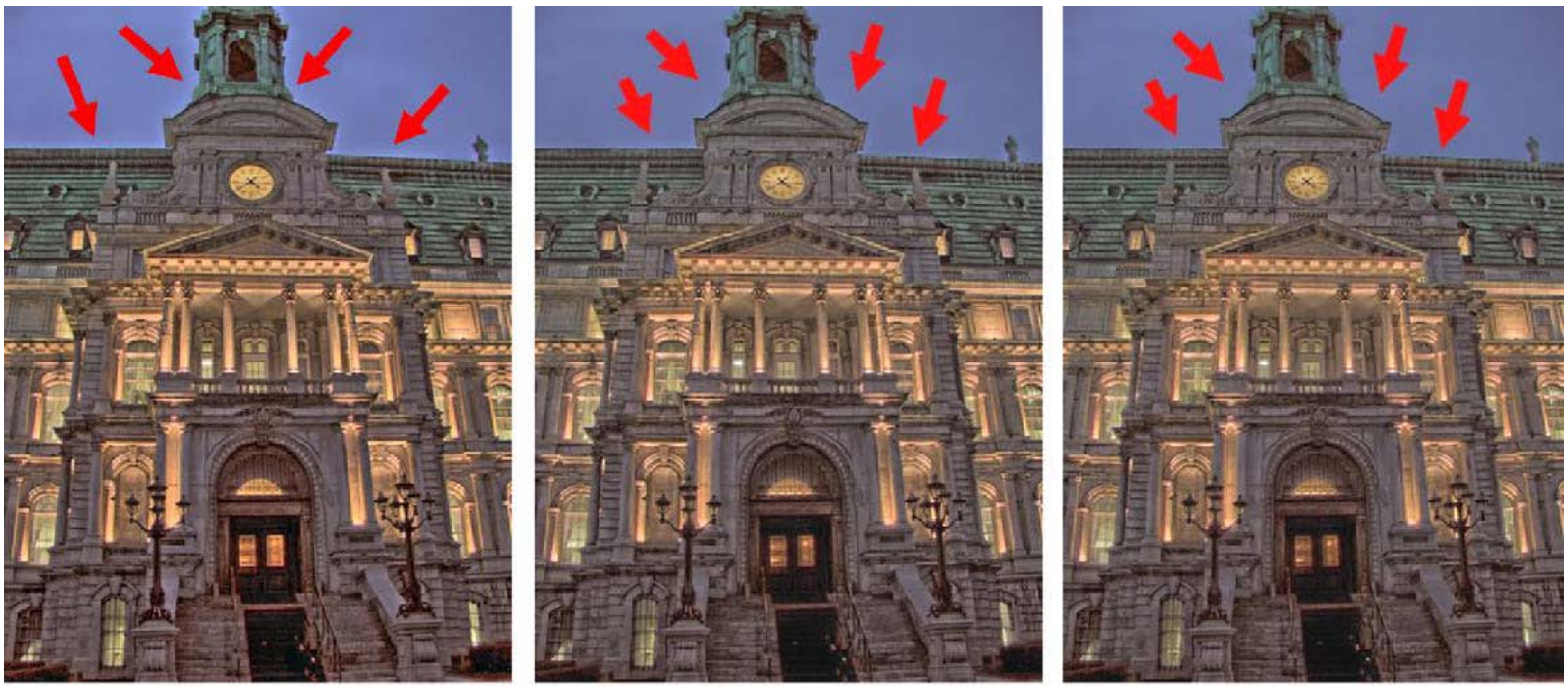
$$w_d(n)=e^{-(d_n/\sigma_d)} \qquad (13)$$

$$w_s(n)=e^{-(S_n/\sigma_s)} \qquad (14)$$

$$S_n=\frac{\left|D(x,y)-Dmean_n\right|}{D_{\max}} \qquad (15)$$

$w_d(n)$ is the distance weighting function,
$w_s(n)$ is the similarity weighting function,
$D_{\max}$ is the maximum value in $D(x,y)$,
s_n is the normalized difference between current pixel value and the average pixel value ($Dmean_n$) of block n.

- Mapped results with considering similarity weighting function
  - Preservation of local contrast
  - Attenuation of halo artifact



σ_s =0.1 σ_s =0.05

Fig. 15. Left: mapping result without considering similarity weighting function. Middle and Right: mapped results with considering similarity weighting function and setting ss to different values. Smaller ss produces image with less halo artifacts but with less local contrast.

Computational efficiency

- HALEQ implementation
  - Approximation of floating point number by densely quantizing floating point to integer
    - Use of LUT to store tone mapping function
- ALHA implementation
  - Pre-calculate distance weighting function
    - Use of repetitive computation value
  - Calculation of similarity function
    - Approximation, pre-calculation and store in LUT
      - Avoiding extensive exponential calculation

Compare ALHA tone mapping operator with other tone mapping operators

- Assessment of tone mapping algorithms
  - Important research topic in tone mapping literature
  - Hard to find computational model
    - Determine superiority of tone mapping algorithms
      - Using human observer and psychophysical experimentation
  - Comparison with Durand & Dorsey’s method

– Selection of 21 test images

- Standard HDR radiance maps
- Sample image sets in some of HDRI software companies' webpage

Fig. 16. Test images used in our psychophysical experimentation.

– Summary of experiment result

- Preference for images showing more local contrast
  - Small difference of detail between images

Table 1
Statistic result of psychophysical experimentation.

Images	Counts statistics			Percentage statistics			Overall performance	
	Ours win	MIT's win	Don't care	Ours win	MIT's win	Don't care	Ours	MIT's
Bright sun	9	22	0	0.2903	0.7097	0.0000	0.2903	0.7097
Bristolb	12	18	1	0.3871	0.5806	0.0323	0.4032	0.5968
Clockbui	13	15	3	0.4194	0.4839	0.0968	0.4677	0.5323
Desk	13	18	0	0.4194	0.5806	0.0000	0.4194	0.5806
Room2	13	18	0	0.4194	0.5806	0.0000	0.4194	0.5806
Pavilion	23	8	0	0.7419	0.2581	0.0000	0.7419	0.2581
Grandcanal	21	10	0	0.6774	0.3226	0.0000	0.6774	0.3226
GroveD	22	9	0	0.7097	0.2903	0.0000	0.7097	0.2903
Memorial	10	21	0	0.3226	0.6774	0.0000	0.3226	0.6774
Oaks	16	13	2	0.5161	0.4194	0.0645	0.5484	0.4516
Office	7	23	1	0.2258	0.7419	0.0323	0.2419	0.7581
Peyrou	16	14	1	0.5161	0.4516	0.0323	0.5323	0.4677
Rosette	11	19	1	0.3548	0.6129	0.0323	0.3710	0.6290
Tahoe1	13	15	3	0.4194	0.4839	0.0968	0.4677	0.5323
Tinterna	22	8	1	0.7097	0.2581	0.0323	0.7258	0.2742
Vinesunset	15	16	0	0.4839	0.5161	0.0000	0.4839	0.5161
Windmill	17	14	0	0.5484	0.4516	0.0000	0.5484	0.4516
Apartment	27	3	1	0.8710	0.0968	0.0323	0.8871	0.1129
Room1	8	22	1	0.2581	0.7097	0.0323	0.2742	0.7258
Lab	12	18	1	0.3871	0.5806	0.0323	0.4032	0.5968
Tree	18	12	1	0.5806	0.3871	0.0323	0.5968	0.4032
Global statistics	318	316	17	0.4885	0.4854	0.0261	0.5015	0.4985

– One example of images pairs rendered by both methods in experiment

Fig. 17. Pairs comparison of tone mapping results of Memorial Church image. Left: result mapped by our ALHA operator and an amplified area. Right: result mapped by fast bilateral filtering tone mapping [12] and an amplified area..

– Comparison with tone mapping operator

Fig. 18. Tone mapping results of the Memorial Church image. From left to right: result of Ward Larson's method [8], result of learning based method [10], result of our ALHA operator, result of Ashikhmin's methods [24]. All the images are courtesy of various authors.

– Results produced by ALHA

• Use of default parameter sets

Fig. 19. Various HDR images tone mapped with our ALHA operator. Radiance maps courtesy of corresponding author(s).

Conclusion and future work

- Proposed method
  - Novel histogram adjustment method
    - Global tone mapping operator HALEQ
      - Fast and well reproduce global contrast
      - Lack of local contrast
    - Local tone mapping operator ALHA
      - Adapt global HALEQ to local implementation
      - Applying HALEQ directly into local areas
      - High quality results with very faster computation speed and fewer parameter adjustments
- Future work
  - Achieve real-time computation for local tone mapping algorithm