A Simple Spatial Tone Mapping Operator for High Dynamic Range Images

K.K. Biswas and Sumanta Pattanaik, School of Computer Science, University of Central Florida, Orlando, Florida, USA

Abstract

We present a simple and effective tone mapping operator, that preserves visibility and contrast impression of high dynamic range images. The method is conceptually simple, and easy to use. We use a s-function type operator which takes into account both the global average of the image, as well as local luminance in the immediate neighborhood of each pixel. The local luminance is computed using a median filter. It is seen that the resulting low dynamic range image preserves fine details, and avoids common artifacts such as halos, gradient reversals or loss of local contrast.

Introduction

The real world scenes often have a very high range of luminance values. While digital imaging technology now enables us to capture full dynamic range of the real world scene, still we are limited by the low dynamic range displays. Thus the scene can be visualized on a display monitor only after the captured high dynamic range is compressed to available range of the display device. This has been referred to as the tone mapping problem in the literature and a great deal of work has been done in this area by using a mapping that varies spatially depending on the neighborhood of a pixel, often at multiple scales [1,2,3,4]. Johnson and Fairchild[5] have shown how accurate color predictions can be made for tone mapping high dynamic range images. The rendering performance of some of these algorithms has been recently reported in Ref. [6]. In this paper we propose a simple tone mapping operator which allows us to preserve the visual content of the real-world scene without the user having to manually set a number of parameters. We show that by using a log of relative luminance at a pixel with respect to its local luminance in a small neighborhood, the standard s-function can be modified to yield visually pleasing results. Further it is also proposed that the local luminance be computed using a median filter, which provides a stronger central indicator than the mean filter.

The Operator

The global contrast helps us to differentiate between various regions of the HDR (high dynamic range) image, which we can loosely classify as dark, dim, lighted, bright etc. Within each region objects become distinguishable due to local contrast against the background – either the object is darker than the background or it is brighter than the background.

If the HDR image consisted of only regions of uniform illuminations, the following s-function would compress the range of illumination across the image, to displayable luminance YD in the range 0 -1.

$$YD(x, y) = Y(x, y) / [Y(x, y) + GC] \quad (1)$$

where GC is the global contrast factor computed through

$$GC = c\, YA \quad (2)$$

where YA is the average luminance value of the whole image and c is a multiplying factor. This would have the effect of bringing the high luminance values closer to 1, while the low luminance values would be a fraction closer to zero. The choice of factor c has an effect on bridging the gap between the two ends of the luminance values. This is somewhat similar to "key-value" concept used in Ref. [3], who suggest that depending on whether the captured HDR image is low-key or high-key, the average value is scaled by a factor α, where α can take one of the values from 0.045, 0.09, 0.18, 0.36 and 0.72.

It is evident from Equation 1, that a lower value of c will help in boosting up the luminance values at the lower end of the captured scene. We have found from our study that a reasonable choice for c is to pick up a value between the range 0.15-0.25. For most images we simply chose c to be 0.15.

While Equation 1 is able to provide a global contrast reduction, it does not attempt to preserve local luminance variations within a region, causing many details to be lost.

A detail in the image can result from two possible reasons- either the pixel is brighter than its surrounding pixels or the pixel is darker than its surrounding pixels. If luminance Y at a pixel is more than YL, the local luminance in its immediate neighborhood, we would like to increase the displayable value YD at that point, so that it appears brighter against its neighborhood. On the other hand, if the luminance Y at a point is less than the local luminance YL in its immediate neighborhood, we would like to reduce the displayable value YD, so that it appears darker than its neighborhood. We propose to achieve this by modifying the s-function as follows:

$$YD(x, y) = Y(x, y) / [Y(x, y) + CL(x, y)] \quad (3)$$

Where CL the contrast luminance at a point (x, y) is obtained by modifying the global contrast factor GC with a term involving the logarithm of ratio of local low-pass filtered value YL to original luminance values,

$$CL = YL\, [\log(\delta + YL/Y)] + GC \quad (4)$$

where δ is a very small value and is included to avoid singularity while doing the log operation.

We suggest that the local luminance YL be computed using a median filter in a 10x10 neighborhood rather than a mean filter. The median filter has been shown to have good averaging property while handling the outliers in the neighborhood. It does not use convolution, but instead is one of a class of filters called the rank filters, that ranks the values of the neighbors of a specified pixel, and inserts the median value of the neighboring pixels at the location of the specified pixel. The median is a stronger "central indicator" than the average. In particular, the median is hardly affected by a small number of discrepant values.

We can consider the 3 separate cases now.

Case 1:

Pixel (x, y) belongs to a uniform region, *i.e*. the LuminanceY and the local luminance YL have same magnitude. In this case the log value is going to be close to zero and thus the contribution of the first term is negligible. CL will be very close to GC, and the new YD value using equation 3, is almost same as computed by equation 1.

Case 2:

Pixel (x, y) is darker than its immediate surrounding neighborhood, *i.e*. the magnitude of pixel luminance Y is less than the local luminance YL. In this case, the first term in equation 4 is positive. The contribution from YL is moderated by a factor which depends on how relatively high YL is with respect to Y itself at that pixel. If the difference is large, the first term in equation 4, is significantly large. In any case a positive term adds on to GC, the global contrast value, resulting in an overall reduction in YD using equation 3 (compared to case 1).

Case 3:

Pixel (x, y) is brighter than its immediate neighborhood, *i.e*. the magnitude of Y is more than the local luminance YL. Since the denominator is higher in log(YL/Y), the first term is going to provide a negative contribution, reducing the value of CL and consequently resulting in a higher value of YD (compared to case 1).

For most HDR images, the computed YD can be displayed directly. If c is chosen small to accommodate the low luminance values of the original HDR image, it is possible that the values around the highest luminance value may result in YD being assigned values slightly more than 1 and may cause white-out in some regions. In such cases, a clipping can be carried out as suggested in Ref. [5]. The displayable image is clipped to 98 or 99 percentile.

Implementation and Results

We have implemented our tone mapping operator on a number of high dynamic range images commonly used by researchers working with HDR images. The luminance values were obtained from the RGB inputs with

$$Y = 0.299 * R + 0.587 * G + 0.114 * B$$

The tone mapping algorithm was implemented using MATLAB. Having computed YD the displayable luminance, the new R, G, B values were computed using Ref. [7]

$$RD = (R / Y)^{\gamma} YD;$$

$$GD = (G / Y)^{\gamma} YD;$$

$$BD = (B / Y)^{\gamma} YD;$$

where γ controls the display color on the monitor. For images presented at the end of the paper we used $\gamma = 0.4$.

The results are shown in Figures at the end of the paper. The operator performs reasonably well. It does not cause any "halo" effects in the rendered images. It is observed that while no details are lost, the images have a pleasing rendering effect, in that no artifacts are visible in the images. There is no loss of local contrast in the displayed images. The effect of choosing different values of c have been illustrated for the "grove" image with c = 0.25, 2.0 and 0.1. A very high value of c causes the overall image to be much darker, while a very small value causes it to become excessively brighter.

Summary

We have presented a simple s-function tone mapping operator, which takes into account the global average and the local average of the pixel luminance. The operator does not need multiple parameters that need to be tuned by the user. We used the same parameter settings for all the images.

References

1. Pattanaik, S.N., Ferwerda, J.A., Fairchild, M.D., and Greenberg, D.P. A multiscale model of adaptation and spatial vision for realistic images display in *Proceedings of SIGGRAPH* 1998*,* Annual Conference Series, ACM, pp 287-298. (1998).
2. Fattal, R., Lischinski, D., and Werman, M. Gradient domain high dynamic range compression in *Proceedings of SIGGRAPH 2002,* Annual Conference Series, ACM, pp 249-246. (2002).
3. Reinhard, E., Stark, M., Shirley, P., and Ferwerda, J. Photographic tone reproduction for digital images in *Proceedings of SIGGRAPH 2002,* Annual Conf. Series, ACM, pp 267-276. (2002).
4. Durand, F., and Dorsey, J. Fast Bilateral filtering for the display of high-dynamic images in *Proceedings of SIGGRAPH 2002,* Annual Conference Series, ACM, pp 257-262. (2002).
5. Johnson, G.M., and Fairchild, M.D. Rendering HDR images in *IS&T/SID 11th Color Imaging Conference*, Scottsdale, 2003, pp 36-41. (2003).
6. Kuang, J., Yamaguchi, H., Johnson, G.M., and Fairchild, M.D. Testing Image Rendering Algorithms in *IS&T/SID 12th Color Imaging Conference*, Scottsdale, 2004, pp 315-320. (2004).
7. Duan, J., and Qiu, G., Fast tone mapping for high dynamic range images, in Proceedings of 17th International Conference on Pattern Recognition, ICPR'04, pp 847-850. (2002).

Author Biographies

K.K. Biswas is a Professor of Computer Science & Engg. at Indian Institute of Technology, New Delhi, India. His interests are in the area of high dynamic range image rendering and video indexing.He is currently a visiting faculty in the School of Computer Science of University of Central Florida.

Sumanta Pattanaik is an Associate Professor of Comptuer Science in the University of Central Florida. His main area of research is realistic rendering. He is the Computer Graphics Category Editor of ACM Computing Reviews.


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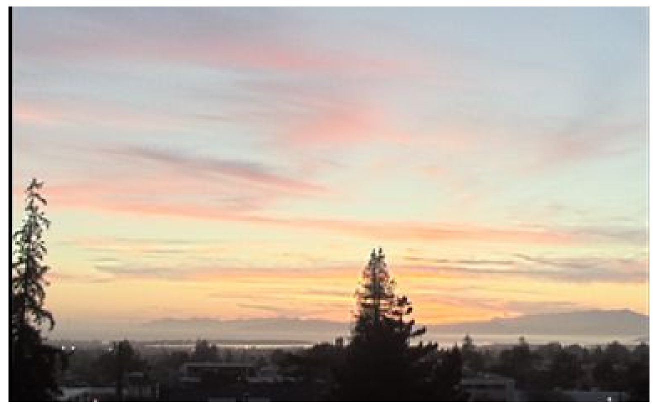

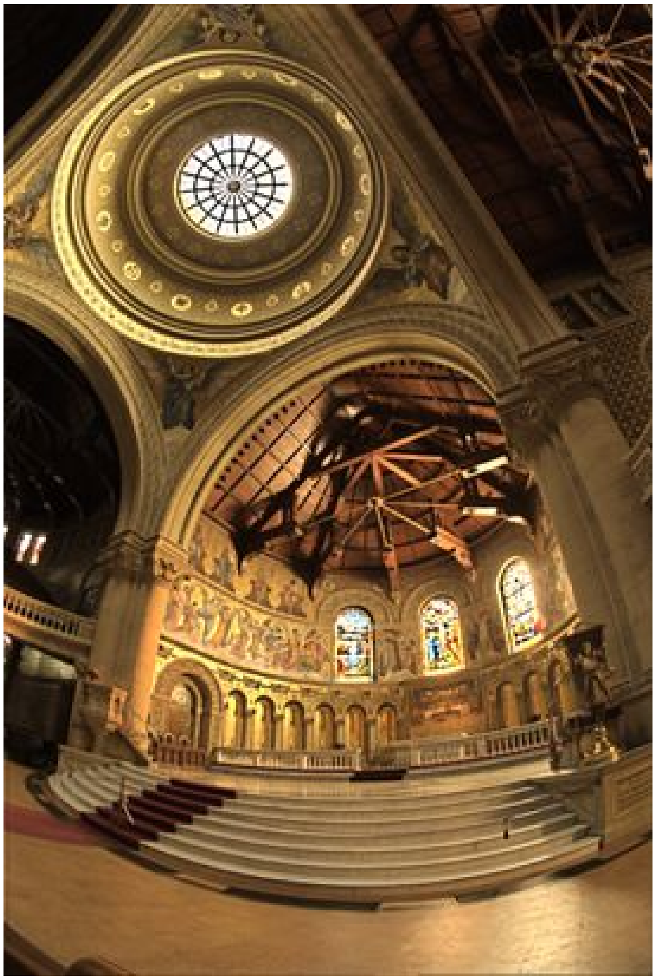

Grow image with c = 0.25

Grow image with c = 0.1

Grow image with c = 2.0