Robust Parameter Estimation for Tone Mapping Operator

Boris Barladian
Keldysh Institute of Applied Mathematics RAS, Russia
obb@gin.keldysh.ru

Abstract

Tone Mapping Operators are used to compress a large range of pixel luminances into a smaller range that is suitable for display on devices with limited dynamic range. This work presents effective and easy to use Tone Mapping Operator based on last ideas in this direction. The estimation process uses sampling method. Essential attention was devoted to providing robustness of algorithm parameter estimation, especially critical for animation applications. The resulting operator produces good images and practically does not require manual parameter tuning.

Keywords: *Tone mapping*, *high dynamic range compression*, *image processing*, *animation.*

1. INTRODUCTION

The range of intensities that can be displayed on current display devices is much smaller than the dynamic range of real scenes. Hence we need to compress real world data to fit the displayable range of such display devices. This compression is called tone mapping, or tone reproduction.

High dynamic range (HDR) radiance maps are becoming increasingly common and important in computer graphics. Initially, such maps were produced mainly by physically-based lighting simulation systems. Today HDR maps of real scenes may be produced even by almost ordinary camera. All what you need is a few differently exposed photographs of the scene [4], or a panoramic video scan of it [1, 12]. It seems that tomorrow's digital still and video cameras will capture HDR images and video directly: [2, 9, 13].

All this stimulate appearance of large number of works devoted to rendering HDR images. Several papers were presented on SIGGRAPH 2002: [6, 7, 10]. Most of algorithms presented in these works may be used with success both for HDR images of real scenes and created by physically-based lighting simulations system, although each of them has own specific.

Tone mapping operators can be classified into two broad groups: (1) global (spatially invariant) mappings, and (2) local (spatially variant) operators. [16, 17, 18, 8, 3].

Global operators compress the luminance of each pixel using a fixed curve, which can depend on some average image characteristics. A log average luminance level is often used as one of the main image characteristic. While the simplicity of these algorithms is attractive, details are frequently lost in light or dark areas of very high dynamic range images.

Local operators scale each pixel according to the average luminance level of its local neighborhood. The most difficult and computationally expensive problem with this type of algorithm is to correctly determine the size of the local neighborhood for each pixel. If done incorrectly, ringing artifacts may occur.

Using local operators for the images created by physically-based lighting simulations system has additional own specific, besides pointed above problems with artifacts and expensive calculations of local parameters for each pixel. Usually special anti-aliasing algorithms are used for providing high quality images. These algorithms, as rule, increase image calculated size more than an order and then provide high quality final image by averaging sub-pixels for each pixel. Tone Mapping Operator should be applied on sub pixel level. In opposite case quality of final image may be essentially decreased. Applying local operators to images of such large dimensions cause additional problems, because requires large memory. Memory problems also are increased, when the set of images should be created for animation purpose. In this case Tone Mapping Operator should provide smooth image brightness changing from frame to frame.

Taking into account all these problems we develop global Tone Mapping Operator and robust algorithm for its parameters estimation.

2. ALGORITHM

Our Tone Mapping Operator is based on Revised Tumblin-Rushmeier Tone Reproduction Operator [18] and additional formula which compress mainly high luminances introduced by Reinhard et al. [10, 11].

The tone mapping operator initially proposed by Tumblin and Rushmeier [15] introduced a model of brightness preservation based on a mathematical model of human vision by Stevens and Stevens [14]. The goal is to keep a constant relationship between the brightness of a scene perceived on a display and its real counterpart, for any lighting condition. Our operator is based on revised Tumblin-Rushmeier operator which reduces displayed contrasts for very dark scenes, preventing contrast reversals and exaggerations.

The revised tone reproduction operator is given by the following formula [17, 18]:

$$L_d = m(L_{wa}) \cdot L_{da} \cdot \left(\frac{L_w}{L_{wa}}\right)^{\left(\frac{\gamma_w}{\gamma_d}\right)} \tag{1}$$

where

L_{da} is the display adaptation luminance, typically between 10-30 cd/m^2,

L_{wa} is scene adaptation luminance, found from scene luminances L_w using:

$$\log(L_{wa}) = mean\left\{\log(L_w + 2.3 \cdot 10^{-5}\, cd/m^2)\right\}, \tag{2}$$

γ_d is $\gamma(Lda)$ and γ_w is $\gamma(Lwa)$, Stevens' contrast sensitivity for a human adapted to the display and the scene respectively. Find these γ values using:

$$\gamma(La) = \begin{cases} 2.655 & for\ La > 100cd/m^2 \\ 1.855 + 0.4\log_{10}(La + 2.3\cdot 10^{-5}) & otherwise, \end{cases} \quad (3)$$

$m(Lwa)$ is the adaptation-dependent scaling term to prevent anomalous gray night images:

$$m(Lwa) = \left(\sqrt{C\max}\right)^{(\gamma_{wd}-1)} \quad (4)$$

where $C\max$ is the maximum available display contrast (30 to 100 typical),

$$\gamma_{wd} = \left(\frac{\gamma_w}{1.855 + 0.4\log(Lda)}\right).$$

The m term steadily increases display brightness as the scene adaptation luminance Lwa increases towards the upper limits of vision.

We applied these formulas to the luminances computed from RGB triplets using:

$$Lw(x,y) = 0.252R(x,y) + 0.664G(x,y) + 0.084B(x,y). \quad (5)$$

For avoiding too large extra calculation and memory requirements we use sampling for scene adaptation luminance Lwa calculations. Only small part of pixels (typically ~ 1%) was used for these calculations. Some details of these calculations, provides robustness parameter estimation are discussed in next section.

In common case Revised Tumblin-Rushmeier Operator produces for part of scene values outside of displayable range. Our operator is used formula introduced by Reinhard et al. [Reinhard 2002] for compressing high luminances:

$$Ldf(x,y) = \frac{Ld(x,y)\left(1 + \frac{Ld(x,y)}{L^2_{white}}\right)}{1 + Ld(x,y)}, \quad (6)$$

where L_{white} is the smallest luminance that is mapped to pure white. For very high dynamic range images the white point L_{white} may be set to the almost any sufficiently large value (typically really close to the maximum scene luminance). For low and medium dynamic range images correct tuning of this parameter become critical. Too small values lead to oversaturated images and too large effectively decrease scene contrast. Details of this parameter tuning are discussed in next section.

3. PARAMETER ESTIMATION

As was pointed above our Tone Mapping Operator is controlled by two parameters – scene adaptation luminance Lwa and the white point L_{white}. Sampling is used for estimation both these parameters. Estimation is done by two steps.

Initially scene adaptation luminance is estimated using equation (2) and white point is set so that approximately 1% of pixels have luminance exceeded this value.

That approach works acceptable for most scenes, but gives not correct results for scenes with large dark areas – the most interesting part of scene become oversaturated. Suggested in [18] constant $2.3\cdot 10^{-5} cd/m^2$ protects from zero values under logarithm during calculations, but is too small for providing reasonable scene adaptation luminance value for these scenes. To correct this problem we exclude too dark pixels from calculations. The following heuristic formula was introduced for cut level determination:

$$Ltrsh = Min(Lwa/20, Lwhite/100)$$

The second correction concerns white point fine tuning. Value calculated on first initial step provides fine results when pixels, where white level is exceeded are mainly pixels where highlight phenomenon take place. So the most of other scene pixels have luminance essentially lower this white point. This approach works bad, when the large part of image pixels have luminance close to this white point level. In this case this part of image becomes oversaturated anew. We correct this problem by tuning white point level so that initially selected white point luminance correspond strictly to the given screen luminance. The empiric value 0.98 (for canonic range [0, 1]) gives fine results for most of tested scenes. Let us denote it as $Ldwt$ - display white threshold. New final white point level L_{fwhite} is calculated by solving equations derived from (1) and (6) taking into account already calculated Lwa, $Ldwt$ and initial value of L_{white} in word space:

$$\begin{cases} Ld = m(Lwa)\cdot Lda\cdot\left(\frac{Lwhite}{Lwa}\right)^{\left(\frac{\gamma_w}{\gamma_d}\right)} \\ Ldwt = \frac{Ld\cdot\left(1 + \frac{Ld}{L^2_{fwhite}}\right)}{1 + Ld} \end{cases}$$

4. RESULTS

Our method was implemented in several products of INTEGRA Inc (www.integra.jp) and works fine for wide range of (HDR) radiance maps generated in these systems. We also have experimented with our method on wide variety of HDR radiance maps of real scenes. In all cases our method produced satisfactory results without additional parameter tuning. Results of some of these experiments are done below.

The images in Figure 1 show four different renderings of the Stanford Memorial church[1]. The dynamic range in this map exceeds 250,000:1. The left top image was produced by Fattall method [7], the right top image was produced by Tumblin and Turk's LCIS method [16], the left bottom image was produced using the method of Ward Larson et al [19] and the right bottom image was produced by our method.

The images in Figures 2 and 3 show a similar comparison using an HDR radiance map of a "streetlight on a foggy night"[1] and the "Belgium House"[2]. The dynamic range in the first map exceeds 100,000:1 and the second one 500,000:1.

The images in Figure 4 show a similar comparison using an HDR radiance map of the "Nave"[1]. The left image was produced by Reinhard method [10] and the right one by our method.

5. ACNOWLEGMENTS

This work was supported in part by INTEGRA Inc. (Tokyo, Japan).

6. REFERENCES

[1] Aggarwal, M., and Ahuja, N. 2001. High dynamic range panoramic imaging. In *Proc. IEEE ICCV*, vol. I, 2–9.

[2] Aggarwal, M., and Ahuja, N. 2001. Split aperture imaging for high dynamic range. In *Proc. IEEE ICCV*, vol. II, 10–17.

[3] Dicarlo, J., and Wandell, B. 2000. Rendering high dynamic range images. *Proceedings of the SPIE: Image Sensors 3965*, 392–401.

[4] Debevec, P. E., and Malik , J. 1997. Recovering high dynamic range adiance maps from photographs. In *SIGGRAPH 97 Conference Proceedings*, AddisonWesley, T. Whitted, Ed., Annual Conference Series, ACM SIGGRAPH, 369–378.

[5] Durand, F. and Dorsey, J. 2000. Interactive tone mapping. In *Eurographics Workshop on Rendering*, 219–230.

[6] Durand, F. and Dorsey, J. 2002. Fast Bilateral Filtering for the Display of Haigh-Dynamic-Range Images. ACM Transactions on Graphics, 21(3), July 2002 (Proceedings of SIGGRAPH 2002).

[7] Fattall, R. Lischinski, D. and Werman, M. 2002 Gradient Domain High Dynamic Range Compression. ACM Transactions on Graphics, 21(3), July 2002 (Proceedings of SIGGRAPH 2002).

[8] Ferwerda, J. 1998. Fundamentals of spatial vision. In *Applications of visual perception in computer graphics*. Siggraph '98 Course Notes.

[9] Nayar, S. K., and Mitsunaga, T. 2000. High dynamic range imaging: Spatially varying pixel exposures. In *Proc. IEEE CVPR*.

[10] Reinhard, E., Stark, M., Shirley, P., and Ferwerda, J., 2002. 'Photographic Tone Reproduction for Digital Images', ACM Transactions on Graphics, 21(3), July 2002 (Proceedings of SIGGRAPH 2002).

[11] Reinhard, E., 2002, Parameter estimation for photographic tone reproduction. Journal of graphics tools, 7(1):45-52, 2002

[12] Schechner, Y. Y., and Nayar, S. K. 2001. Generalized mosaicing. In *Proc. IEEE ICCV*, vol. I, 17–24.

[13] SpheronVR. http: //www.spheron.com/.

[14] Stevens, S.S and Stevens, J.C.. Brightness function: parametric effects of adaptation and contrast. *Journal of the Optical Society of America*, 50(11):1139A, November 1960.

[15] Tumblin, J., and Rushmeier, H. 1993. Tone reproduction for computer generated images. *IEEE Computer Graphics and Applications 13*, 6 (November), 42–48.

[16] Tumblin, J., and Turk, G. 1999. LCIS: A boundary hierarchy for detail-preserving contrast reduction. In *Siggraph 1999, Computer Graphics Proceedings*, Addison Wesley Longman, Los Angeles, A. Rockwood, Ed., Annual Conference Series, 83–90.

[17] Tumblin, J., Hodgins, J. K., and Guenter, B. K. 1999. Two methods for display of high contrast images. *ACM Transactions on Graphics 18*, 1 (Jan.), 56–94.

[18] Tumblin, J. 1999 *Three Methods For Detail-Preserving Contrast Reduction For Displayed Images*. PhD thesis, Georgia Institute of Technology, 1999.

[19] Ward Larson, G., Rushmeier, H., and Piatko, C. 1997. A visibility matching tone reproduction operator for high dynamic range scenes. *IEEE Transactions on Visualization and Computer Graphics 3*, 4, 291–306.

About the author

Boris Barladian is a senior research scientist of Keldysh Institute of Applied Mathematics RAS, Department of Computer graphics.

---

[1]Radiance map courtesy of Paul Debevec, Sumant Pattanaik, Peter Shirley, Jack Tumblin and Greg Ward
[2]Radiance map courtesy of Raanan Fattal Dani Lischinski Michael Werman
School of Computer Science and Engineering. The Hebrew University of Jerusalem

Figure 1: Stanford Memorial Church. The left top image produced by Gradient Domain method [Fattall 2002], right top by LCIS method, left bottom by Ward Larson *et al* and right bottom by our method.

Figure 2: Streetlight on a Foggy Night. The left top image produced by Gradient Domain method [Fattall 2002], right top by LCIS method, left bottom by Ward Larson *et al* and right bottom by our method.

Figure 3: Belgium House. The left top image produced by Gradient Domain method [Fattall 2002], right top by LCIS method, left bottom by Ward Larson *et al* and right bottom by our method.

Figure 4: Nave image. The left image produced by Reinhard , E. [10] and right by our method..