디테일 보존 톤 매핑

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Detail-preserving Tone Mapping

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Abstract: High dynamic range (HDR) scenes need to be contrast reduced to be displayed on a common device with a limited dynamic range. To preserve image details and visual impression of the original scenes, we proposed a new tone mapping method with global and local adaptation models utilizing the gain control properties of real cameras. It generates different exposure value for each image region. Using the directional property of anisotropic diffusion, we can avoid halo artifacts in high gradient regions and preserve image details in textured regions.

Keywords: Tone mapping, HDR, Diffusion.

Ⅰ. Introduction

Real-world scene can exhibit a broad range of luminance value spanning approximately ten orders of absolute range. The human visual system has a sufficient dynamic range to detect subtle contrast variations and interpret scenes under various illumination conditions. In contrast, the range of intensities that can be displayed on current display devices is much smaller than the dynamic range of real scenes. This makes it difficult to depict high contrast scenes on low contrast display without loss of important fine details and textures. To be displayed on a common device with a limited dynamic range, the HDR scenes need to be compressed.

The conversion from HDR scene radiances to image intensities with a low dynamic range (LDR) is known as tone-mapping or tone-reproducing. The key issue of tone-mapping is how to preserve visible image details while maintaining overall impression of the original scene and avoiding halo artifacts near strong edges. Previous tone-mapping methods have generally met some of these issues using spatially invariant global mapping functions [1-10] or spatially variant local operators [11-16]. While the simplicity of global methods is attractive, they may cause noticeable lost of spatial sharpness in light or dark areas of images.

In this paper, to preserve image details and visual impression of the original scenes, we proposed a new tone mapping method with global and local adaptation models utilizing gain control properties of real cameras.

Consider a scene containing both areas of low and high illumination as shown in Fig 1(a). Camera changes its gain automatically or manually to capture important fine details and textures of the real scene. If the gain of the camera is increased to represent details in dark areas, image contents in the brightness region can be lost as shown in Fig 1(b). Sometimes, this linear scaling with a single gain value preserves overall contrast. However, image information in some region can be lost. In contrast, a global operator (i.e. gamma function) allots different gain value to each pixel. Although it contains both areas of low and high illumination, fine image details are not visible as shown in Fig 1(c).

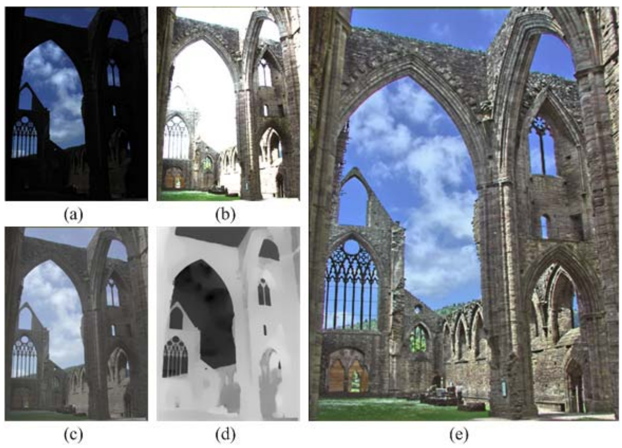

Fig 1. Example of HDR scene. (a) Original HDR image: image courtesy of Grey Ward. (b) Image from linear mapping. (c) Image from gamma correction. (d) Local gain map. (e) Image rendered with the proposed method.

The basic idea of our work is to use different gain in each image region as shown in Fig 1(d) which is obtained using our method. By applying different gain for each pixel, but approximately uniform in each image region, we can preserve image details and the visual impression of the original scene as shown in Fig 1(e). For these goals, we presented a new energy function. Incorporating directional properties into the energy function, we can also avoid halo artifacts in high gradient regions.

Ⅱ. Proposed Method

This section presents a framework for reproducing color HDR images. The first part describes a global operator to preserve overall contrasts. In the second part, we introduce a new local operator to reproduce image details. In the last part of this section, the overall flow of our method is briefly explained for color HDR scenes.

1. Global tone mapping

Let L be the normalized luminance image of an HDR scene. From the product of the original image with a scaling function, we introduce a new representation given by

$$I(\mathbf{x}) = F(L(\mathbf{x}))L(\mathbf{x}), \tag{1}$$

where F is a global gain map and $I(\mathbf{x})$ is the tone-mapped intensity in each image location $\mathbf{x}$.

It is noted that the behavior of F is very similar to the gain of a camera such as exposure time. Any global operator can be expressed in this form. Given a global tone-mapping function H, the corresponding gain function can be obtained by

$$F(x) = \begin{cases} H(x)/x & x > x_T \\ H(x_T)/x_T & \text{otherwise,} \end{cases} \tag{2}$$

where x_T (≈ 0) is a constant to prevent overflows.

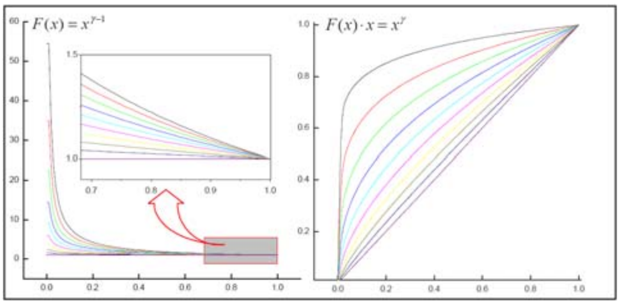

Fig 2. Plot of $F(x)$ and $F(x)x$ with various gamma values (γ = 0.01~1.0).

To successfully reproduce the overall impression of the original scene, an adequate choice of the global operator is very important. In this paper, we used the form of gamma function as shown in Fig 2. In the figure, gamma curves and the corresponding gain functions are plotted with various parameter settings. As γ decreases, the gain value increases, especially in dark areas.

The parameter γ is determined by controlling the average luminance of I, given by

$$\gamma = \frac{\sum_{\mathbf{x}\in\Omega}[\log(L(\mathbf{x}))]^2}{\sum_{\mathbf{x}\in\Omega}[\log(a)\log(L(\mathbf{x}))]}, \tag{3}$$

where Ω is the image domain and a is a constant. The constant a controls the average luminance of the resulting image. We found values between 0.4 and 0.6 to produce satisfactory results.

2. Local operator

Although the global tone mapping operator is very simple, image details can be lost in textured areas of images. Instead of using F, we introduced spatially varying local gain map (LGM) τ, obtained by

$$\tau(\mathbf{x}) = \arg\min_{t(\mathbf{x})} \int_{\mathbf{x}\in\Omega} \left((1-\lambda)T(t(\mathbf{x})) + \lambda\|t(\mathbf{x}) - F(L(\mathbf{x}))\|^2\right)d\mathbf{x}$$

$$\text{subject to } t(x)L(x) \le 1, \tag{4}$$

where λ (0≤λ≤1) is a weighting constant and T is a given function which often defines the particular emphasis on the features of the resulting map.

To use uniform gains in some region and to preserve sharp edges between regions, we applied anisotropic diffusion operator for T. Among various operators [17], we used Huber M-estimator given by

$$T(x) = \begin{cases} x^2/2 & |x| \le k \\ k|x| - k^2/2 & \text{otherwise} \end{cases}, \tag{5}$$

where k is a positive constant.

For large k, this flow yields an isotropic diffusion, and for small k, it corresponds to total variational gradient descent flow preserving sharp edge. To obtain uniform gain values, we have to use relatively large value of k. However, this can cause halo artifacts in the region of high contrast edges in the final output I.

To overcome this, we controlled λ in Equation (4). With large value of λ, τ preserves the original data of F. Thus, by allowing large value of λ in the region of high gradients, we can preserve original edges of F.

We obtained the spatially varying $\lambda(\mathbf{x})$, which we call edge strength map (ESM), using the original HDR image, given by

$$\lambda(\mathbf{x}) = (1-\alpha)\left(1 - \left(\frac{G_{\max} - G(\mathbf{x})}{G_{\max}}\right)^2\right)^p + \alpha, \tag{6}$$

where G is the gradient image obtained by

$$G(\mathbf{x}) = \sum_{i=r,g,b} \left\| \nabla L_i(\mathbf{x}) \right\|^2, \quad (7)$$

α(=0.05) is a constant to give uniform weightings, p(=10) is a constant controlling the strength of edge, and G_{max} is the maximum value of G(x).

3. Color processing

The overall flow of our method with a color HDR image is depicted in Fig 3. Instead of using luminance image, we applied our algorithm to the maximum image of the color HDR image, given by

$$L_{\max}(\mathbf{x}) = \max\left(L_r(\mathbf{x}), L_g(\mathbf{x}), L_b(\mathbf{x})\right). \quad (8)$$

Global gain map can be found with L_{max} through Equation (3). With the local gain map minimizing Equation (4), we finally reproduce the HDR image by multiplying the local gain map with the original HDR image. It should be noted that the intensity saturation can be avoided using L_{max}.

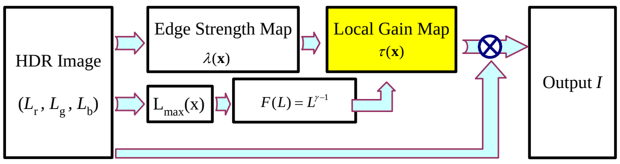

Fig 3. Overall flow of our method.

Ⅲ. Experimental Results

We have tested our method on a variety of HDR radiance maps of real scenes, and compared our results with current state of art methods.

In Fig 4, we showed results from Vine scene and compared it with the fast bilateral filtering method [14]. They preserve visual impression of the original image preventing halo artifacts. To see halo artifacts, we showed a result using isotropic smoothing in (c). Applying anisotropic diffusion and edge strength map, our result preserves more image details than the bilateral filtering method and successfully avoids halo artifacts in high gradient region.

In Fig 5, we compared our result with three other methods. First of all, all techniques perform very well. Sometimes, it is difficult to judge the quality because it is very subjective. The gradient domain technique [13] seems to be the best at preserving detail, maybe sometimes too good. The photographic tone reproduction technique [11] provides a good photographic appearance, but lost image details in some areas. The result of Retinex-based adaptive filter [15] is lacking in some contrasts. However, our method provides a reasonable photographic look, and image details are preserved in the most part of the image.

Fig 6 shows other results. Our method preserved the visual impression of the original image without halo artifacts.

Ⅳ. Conclusion

We described a novel tone mapping method with global and local adaptation models with gain control properties of real cameras. Compared with other local methods, our method preserved image details for the most part of image regions with a reasonable photographic look.

In particular, our algorithm is similar in some respects to that of Chiu et al. [7] who provide spatially non-uniform gain map. The main difference of this work from [7] is that our gain map is non-uniform globally but approximately uniform in some image region, preserving visual contrast in each uniform region. Pardo and Sapiro [16] produced a minimal set of images capturing the information all over the high dynamic range data, while at the same time preserving a natural appearance for each one of the images in the set. They also used the same global operator in each segmented region. However, we overcame the limitation mentioned in [16] by representing a HDR image with one standard output image.

Fig 4. Vine scene. Radiance map courtesy of Paul Debevec, USC.

(a) Gradient domain method (b) Photographic tone reproduction (c) Retinex-based adaptive filter (d) Our method

Fig 5. Memorial scene. Radiance map courtesy of Paul Debevec, USC.

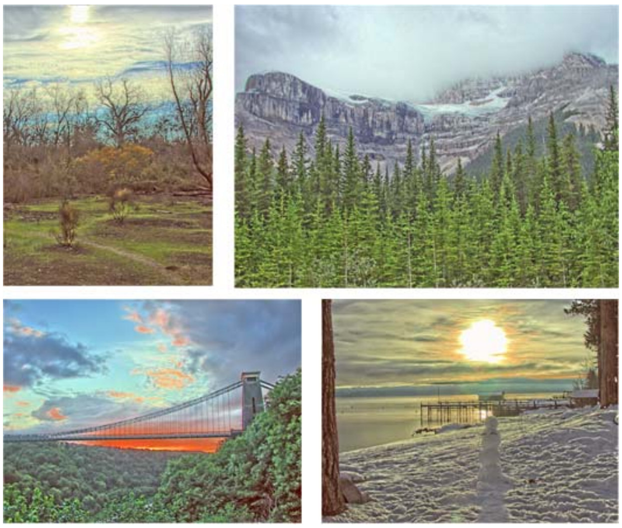

Fig 6. Other results. Radiance map courtesy of Greg Ward.

References

[1] Jack Tumblin and Holly Rushmeier. Tone reproduction for realistic images. IEEE Computer Graphics and Applications, 13(6):42– 48, 1993.

[2] B. Barladian. Robust parameter estimation for tone mapping operator. GraphiCon’2003, 2003.

[3] F. Drago, K. Myszkowski, T. Annen, and N. Chiba. Adaptive logarithmic mapping for displaying high contrast scenes. Computer Graphics Forum, 22(3):419– 426, 2003.

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

[5] G. Qiu and J Duan. An optimal tone reproduction curve operator for the display of high dynamic range images. IEEE International Symposium on Circuits and Systems, 2005.

[6] J. Duan and G. Qiu. Fast tone mapping for high dynamic range images. International Conference on Pattern Recognition, 2004.

[7] K Chiu, M Herf, P Shirley, S Swamy, C Wang, and K Zimmerman. Spatially nonuniform scaling functions for high contrast images. Proceeding of Graphics Interface, pages 245– 254, 1993.

[8] Z. Rahman, D. J. Jobson, and G. A.Woodell. A multiscale retinex for color rendition and dynamic range compression. SPIE International Symposium on Optical Science, Engineering, and Instrumentation, 1996.

[9] S. N. Pattanaik, J.A. Ferwerda, M. D. Fairchild, and D. P. Greenberg. A multiscale model of adaptation and spatial vision for realistic image display. International Conference on Computer Graphics and Interactive Techniques, pages 287– 298, 1998.

[10] J. Tumblin and G. Turk. LCIS: a boundary hierarchy for detail-preserving contrast reduction. ACM Transactions on Graphics, pages 83– 90, 1999.

[11] E. Reinhard, M. Stark, P. Shirley, and J. Ferwerda. Photographic tone reproduction for digital images. ACM Transactions on Graphics, 21(3):267– 276, 2002.

[12] Michael Ashikhmin. A tone mapping algorithm for high dynamic contrast images. Eurographics workshop on Rendering, pages 145 – 156, 2002.

[13] R. Fattal, D. Lischinski, and M. Werman. Gradient domain high dynamic range compression. ACM Transactions on Graphics, 21(3):249– 256, 2002.

[14] F. Durand and J. Dorsey. Fast bilateral filtering for the display of high-dynamic-range images. ACM Transactions on Graphics, 21(3):257– 266, 2002.

[15] L. Meylan and S. S?sstrunk. High dynamic range image rendering using a retinexbased adaptive filter. IEEE Transactions on Image Processing, page Accepted, 2005.

[16] A. Pardo and G. Sapiro. Visualization of high dynamic range images. IEEE Transactions on Image Processing, 12(6):639– 647, 2003.

[17] A. B. Hamza, H. Krim, and G. B. Unal. Unifying probabilistic and variational estimation. IEEE Signal Processing Magazine, 19(5):37– 47, 2002.