https://doi.org/10.2352/issn.2169-2629.2020.28.56

A Study of Unsharp Masking on HDR Visualization on low Dynamic Range Devices

Jakkarin Singnoo; Department of Imaging and Printing Technology, Faculty of Science, Chulalongkorn University; Bangkok, Thailand

Abstract

To visualize HDR contents on low dynamic range displays, a fast and efficient TMO is often preferred. One way to achieve this is to use a Global TMO. However, Global TMO often results in poor contrast tone-mapped images and often needs a post-process that enhances the contrast, such as Unsharp Masking. This work illustrates that such Unsharp Masking can be directly integrated into several global TMOs, resulting in an alternative framework to apply the Unsharp Masking to the HDR visualization pipeline. The proposed framework is fast and delivers images with a proper contrast without the need for the additional image sharpening at the post process.

Introduction

Dynamic Ranges of HDR contents are far more exceed the affordable dynamic range than conventional low dynamic range devices can reproduce. To visualize the HDR contents on such devices, a processing pipeline that compresses the dynamic range in the way that preserves the characteristics of the original content is the must.

Conventional HDR visualization pipeline consists of two main processes: first, the dynamic range is compressed through the process called tone mapping, then the tone-mapped image is passed through a number of post-processes before displaying on the screen. These post-processes can be gamma adjustment, black and white point correction, color reconstruction, and image sharpening, which is the main focus of this work.

Over the years, many researchers have proposed numbers of Tone Mapping Operators (TMOs) [1], [2], [3], [4], [5], [6], [7]. Based on the processing technique, these TMOs can be classified into different categories: Global, Local, Frequency-based, and Segmentation-based operators.

Among all categories, Global TMOs are considered to be the fastest operator since the operators apply the same function to all image pixels. Global operators also typically result in tone-mapped images that are natural and photorealistic since there is no spatial artifact such as halos introduced here. For these reasons, global operators are often used in many practical situations, such as real-time visualization. However, global operators also suffer from the fact that they do not preserve local contrast. This means that global operators can result in the tone-mapped images that are flat and lost finer details contained in the original in many cases. This often leads to the need for an additional image sharpening at the post-process.

Unsharp Masking (USM) is considered to be one of the most well-known image sharpening algorithms. The name derives from the fact that the algorithm uses an unsharp (blurred) version of the original image to create a mask that will later be combined back to the original image to obtain the sharpen output image. Apart from image sharpening, USM can also be used with a small amount and large radius to perform local contrast enhancement [8].

Related works are considered in the next section. Then, the new USM framework is proposed. Then, the comparison between the conventional pipeline and the proposed framework is given. In the last section, the conclusion is given.

Related Works

In this section, two Global TMOs that apply image sharpening as a post-process to cope with the problem of flat-looking images are described.

Generic Tone Mapping Operator

[7] combines per-pixel tone curve, color saturation adjustment, and modulation transfer function as an image sharpening, to model an inexpensive computational TMO. The TMO often results in visually indistinguishable images from its local operator that is far more computationally expensive, indicating that many local operators can be well approximated by a combination of global operator and post processes.

Optimal Global Approximation Operator

[3] uses a constrained optimization technique to derive the optimal tone curve that best approximates the local operators. To bring back the lost detail, they first attempting to use a USM. However, they conclude that USM can slightly ameliorate the problem and use a cross-bilateral filter to perform the task instead.

Framework

In this work, we do not attempt to propose any new tone mapping operator, but instead to propose an alternative framework for applying USM to the HDR visualization pipeline. Specifically, we are interested in modifying any existing global TMOs to directly incorporate USM inside the operators rather than applying the USM to the tone-mapped image as a post-process (after the TMO has been done).

The framework introduced in the previous paragraph is explained here. Similar to the conventional visualization pipeline, the proposed framework also tone-map the HDR on the luminance L. We first obtain the luminance values with $L = 0.21R + 0.72G + 0.07B$. Next, instead of applying global TMO to the luminance, we first directly apply the USM to the luminance L of the HDR to obtain the sharpen luminance L_{sharp}:

$$L_{sharp} = L + \hat{L} \tag{1}$$

where $\hat{L}$ denotes the high-passed component obtained by subtracting the gaussian low-passed component $\check{L}$ (Blurred version) to the luminance L.

The USM has three parameters: Sigma σ, Radius, and Amount. The σ controls the shape of the gaussian filter used for creating the mask. The Radius affects the size of the edges to be enhanced. The Amount controls how much contrast is added at the edges. In this work, we constrain the Radius to be the size of $\lceil 2\sigma \rceil$.

Finally, the L_{sharp} will be passed to the modified version of the global TMO to incorporate the USM into the visualization framework. In this way, the proposed framework uses USM as a Pre-process before the tone mapping.

This section, demonstrates how flexible the USM can be integrated into the framework. We use two of the well-known global TMOs: Adaptive logarithmic Tone Mapping Operator [1] and the global luminance compression found in the initial step of the Photographic tone mapping operator [2].

Modified Photographic Tone Reproduction

The tone mapping function presented in Equation 2 is used to compute a displaying luminance L_d for each pixel. This function is the modified version of the luminance mapping equation presented in [2]. What we have done here is to replace the scene luminance L_w of the numerator with the sharpen luminance L_{sharp}:

$$L_d = \frac{L_{sharp}\left(1 + \frac{L_{sharp}}{L_{white}^2}\right)}{1 + L_w} \tag{2}$$

where L_{white} is the smallest luminance that will be mapped to the pure white of the display. Here, we set L_white to the maximum luminance in the scene.

Modified Adaptive Logarithmic Mapping

Similar to the modified photographic operator presented in the previous section, the tone mapping function presented in Equation 2 is the modified version of the Equation (4) presented in [1], where the L_w of the numerator is replaced by L_{sharp}:

$$L_d = \frac{L_{dmax} \cdot 0.01}{\log_{10}(L_{max}+1)} \cdot \frac{\log\left(L_{sharp}+1\right)}{\log\left(2 + \left(\frac{L_2}{L_{wmax}}\right)^{\frac{\log(b)}{\log(0.5)}} \cdot 8\right)} \tag{3}$$

where L_{dmax} is the maximum luminance value of the display. Here we use a value for $L_{dmax} = 100cd/m^2$. The L_{wmax} is the maximum luminance in the scene. b is the bias parameter used to adjust the compression. Here we use a default bias of 0.85, as found in the original paper.

Results

As mention in the previous section, two TMOs have been modified in our work. For each TMO, there are three output images: the tone-mapped image of the original TMO, a conventional framework (original TMO followed by USM), and the proposed USM framework. Thus, for each HDR scene, there are six output images in total. Figure 1 shows all of the output images of the MEMORIAL scene. We noted that here we use the same USM parameters. As can be seen, the sharpening effect of USM in the proposed framework is more dominant than its conventional counterpart. We also noted that, in all the tested scenes, we see very little sharpening improvement between the global TMO alone and the conventional USM, while the results produced by the proposed USM contain more edge enhancement that is similarly found in more expensive algorithms such as the bilateral filter. Figure 2 further visualizes this effect by showing the difference between outputs of the two frameworks. Figure 3 shows a selection of tone-mapped images.

To evaluate the efficiency of the proposed framework, we have measured the computational speed of the global TMO alone, the conventional framework, and the proposed framework. All frameworks implemented in Matlab and running on an Intel Core i9 2.3 GHz Processor. Table 1 reports the computational time used for each workflow of the Modified Photographic Operator. Table 2 also reports the computational times but excludes times used by global TMO along with different percentages between the two workflows. As can be seen, the proposed framework outperforms the conventional framework in all tested scenes by around 138%.

Table 1. Timing in seconds for each visualization framework

Scene	Size	TMO Alone	Conventional Frame-work	Proposed Frame-work
MEMORIAL	512x768	0.0379	0.0409	0.0394
NAVE	720x480	0.0331	0.0357	0.0341
ATRIUM	1016x760	0.0811	0.0865	0.0833
CHURCH	1200x1013	0.1280	0.1354	0.1308
BOTTLE	688x912	0.0540	0.0582	0.0559

Table 2. Computational time exclude time used by TMO

Scene	Conventional Framework	Proposed Framework	Difference (%)
MEMORIAL	0.0030	0.0015	100
NAVE	0.0026	0.0010	160
ATRIUM	0.0054	0.0022	145
CHURCH	0.0074	0.0028	164
BOTTLE	0.0042	0.0019	121

Note that we did not use Fast Fourier Transform (FFT) because the mask's size used in this work is typically small. However, in practice, computing the mask using FFT can increase the framework's performance, especially when applying to large images.

Conclusion

We have developed an alternative framework to apply USM for visualizing HDR contents on low dynamic range devices. The proposed framework eliminates the need for image sharpening that is often used in the conventional pipeline's post process. The proposed framework can be done by first applying USM to the luminance of the HDR, then incorporating the unsharp masked image to existing global TMOs.

The proposed framework delivers a sharp, well-balanced image that is visually appealing and outperforms the conventional pipeline in terms of computational speed, indicating that it can practically replace its conventional counterpart.

As future work, we are interested in increasing the framework's performance by completely reimplementing the framework in C to cope with real-time HDR video visualization. We also intend to extend the proposed framework on other global TMOs. We are also interested in conducting a psychophysical experiment to measure the subjective image quality in terms of the photorealistic and visual appeal of the proposed framework with other state-of-the-art TMOs.

Acknowledgments

This work was supported by the office of research affairs, Chulalongkorn University [Grants for Development of New Faculty Staff, Ratchadaphiseksomphot Endowment Fund].

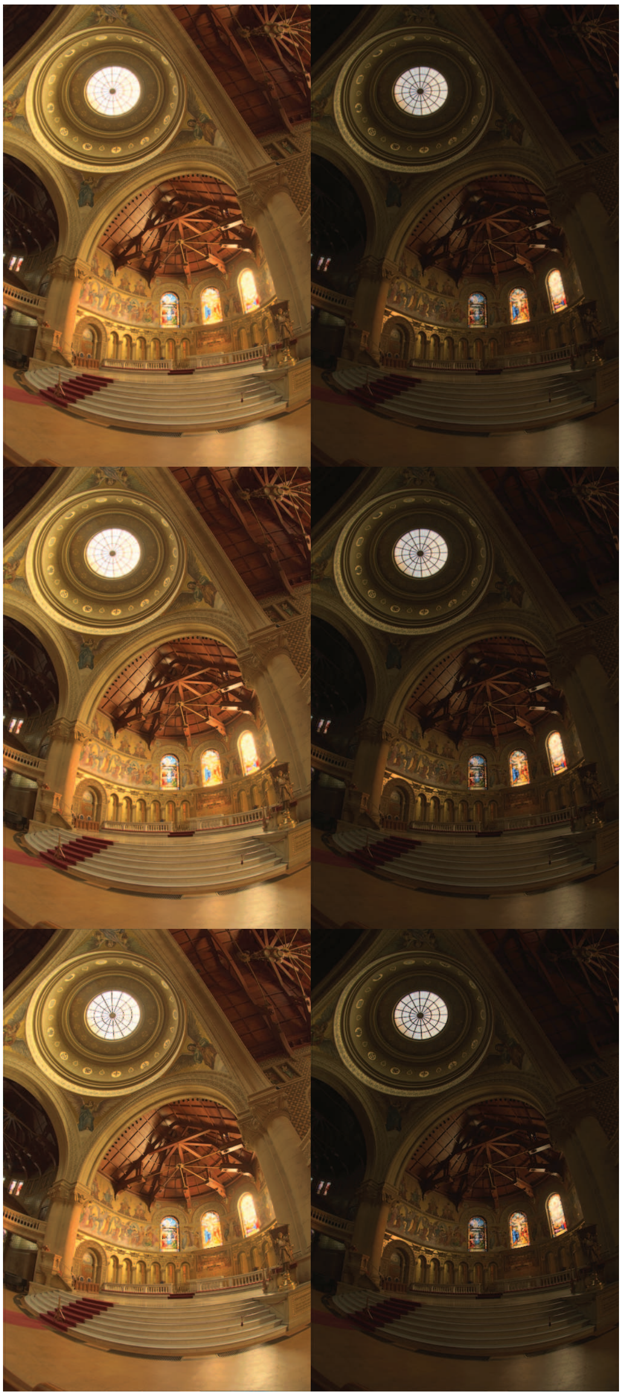

Figure 1. *Tone-mapped images of the MEMORIAL scene resulted from all visualization frameworks used in this work. Photographic Tone Reproduction Operator is used to generate images on the Left. Adaptive Logarithmic Mapping Operator is used to generate images on the right. Original tone-mapped image (Top), Conventional Framework (Middle), Proposed Framework (Bottom). The original scene is courtesy of Paul Debevec.*

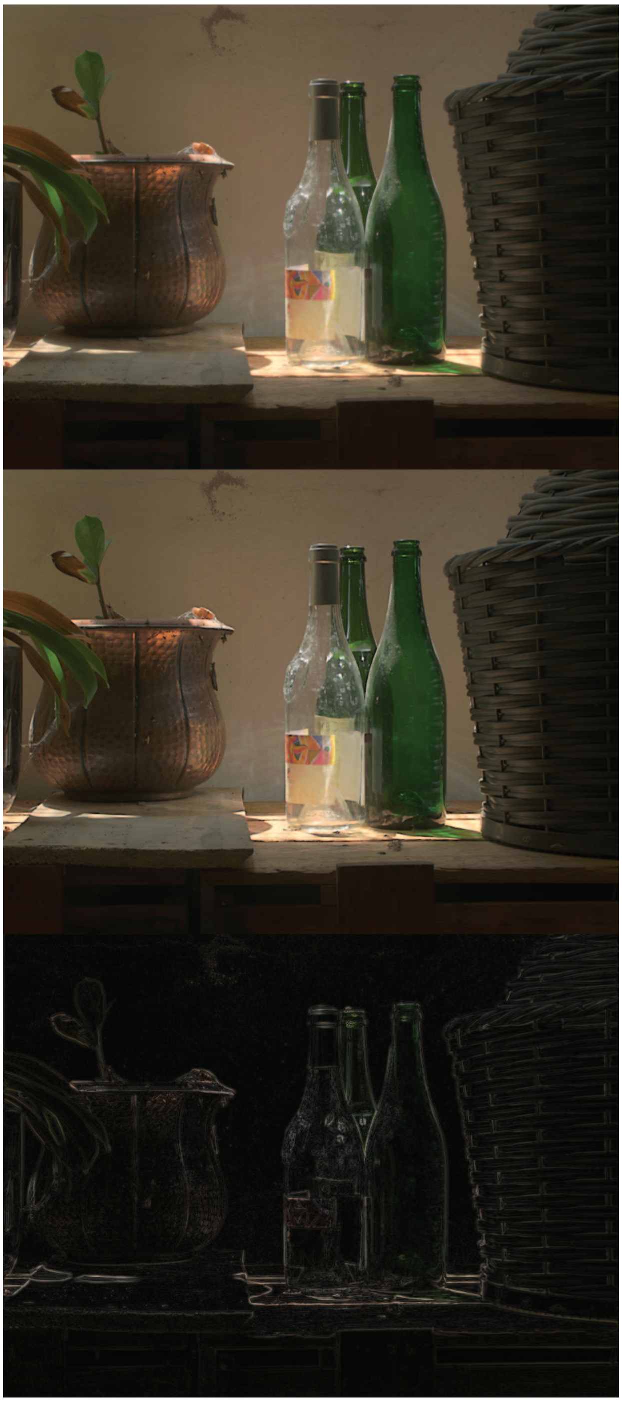

Figure 2. *The BOTTLE scene processed with the conventional pipeline (Top), the proposed framework with the same parameters (Middle), along with the absolute difference image between the two images (Bottom). Noted that the difference image was raised by the gamma of (1/2.2). The original image is acquired from [9]*

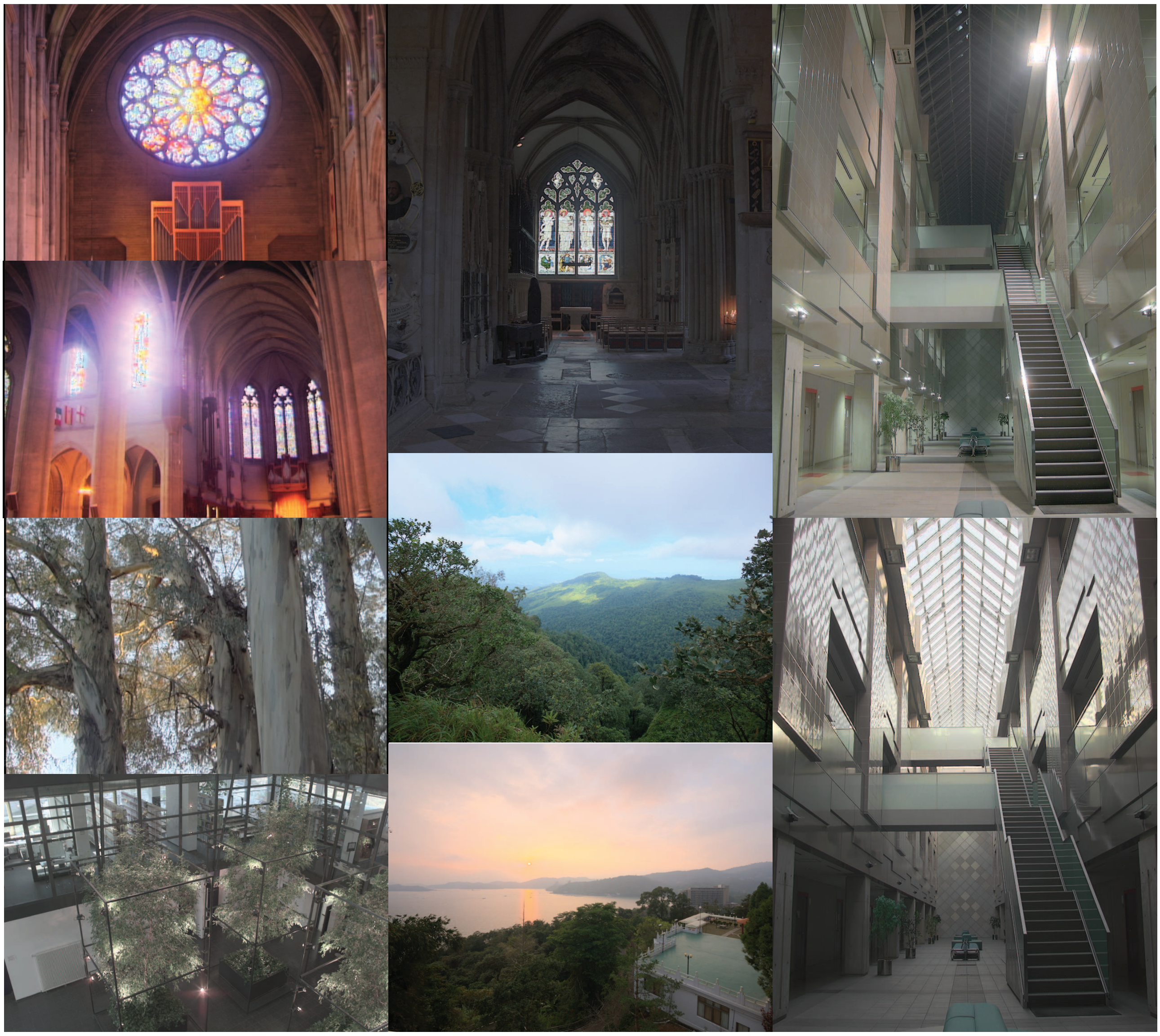

Figure 3. *A selection of HDR images tone-mapped using the proposed visualization framework. The original scenes are courtesy of Paul Debevec, [4], [7], and [10].*

References

[1] Frédéric Drago, Karol Myszkowski, Thomas Annen, and Norishige Chiba. Adaptive logarithmic mapping for displaying high contrast scenes. *Comput. Graph. Forum*, 22:419–426, 2003.

[2] Erik Reinhard, Michael Stark, Peter Shirley, and James Ferwerda. Photographic tone reproduction for digital images. In *Proceedings of the 29th annual conference on Computer graphics and interactive techniques*, pages 267–276, 2002.

[3] Jakkarin Singnoo and Graham D Finlayson. Optimal global approximation to spatially varying tone mapping operators. In *Conference on Colour in Graphics, Imaging, and Vision*, volume 2012, pages 182–188. Society for Imaging Science and Technology, 2012.

[4] Jakkarin Singnoo. Fast segmentation-based tone mapping operator. *AIC 2017 Jeju*, pages 76–76, 2017.

[5] Frédo Durand and Julie Dorsey. Fast bilateral filtering for the display of high-dynamic-range images. In *Proceedings of the 29th annual conference on Computer graphics and interactive techniques*, pages 257–266, 2002.

[6] Gregory Ward Larson, Holly Rushmeier, and Christine Piatko. A visibility matching tone reproduction operator for high dynamic range scenes. *IEEE Transactions on Visualization and Computer Graphics*, 3(4):291–306, 1997.

[7] Rafał Mantiuk and Hans-Peter Seidel. Modeling a generic tone-mapping operator. In *Computer Graphics Forum*, volume 27, pages 699–708. Wiley Online Library, 2008.

[8] S.T. McHugh. *Understanding Photography: Master Your Digital Camera and Capture That Perfect Photo*. No Starch Press, Incorporated, 2018.

[9] Francesco Banterle, Alessandro Artusi, Kurt Debattista, and Alan Chalmers. *Advanced high dynamic range imaging*. CRC press, 2017.

[10] Erik Reinhard, Wolfgang Heidrich, Paul Debevec, Sumanta Pattanaik, Greg Ward, and Karol Myszkowski. *High dynamic range imaging: acquisition, display, and image-based lighting*. Morgan Kaufmann, 2010.

Author Biography

Jakkarin Singnoo received a B.Sc. in Imaging and Printing Technology from Chulalongkorn University, Thailand, M.Sc. in Advanced Computer Graphics and Applications and Ph.D. in Computer Science from University of East Anglia, UK. He is currently a lecturer at the Department of Imaging and Printing Technology, Faculty of Science, Chulalongkorn University. His research interests include High Dynamic Range (HDR) Imaging, Color Image Processing, Computer Vision, and Psychophysics.