Tone Mapping HDR Images Using Local Texture and Brightness Measures

Akshay Gadi Patil and Shanmuganathan Raman

Abstract The process of adapting the dynamic range of a real-world scene or a photograph in a controlled manner to suit the lower dynamic range of display devices is called tone mapping. In this paper, we present a novel local tone mapping technique for high-dynamic range (HDR) images taking texture and brightness as cues. We make use of bilateral filtering to obtain *base* and *detail* layer of the luminance component. In our proposed approach, we weight the base layer using local to global brightness ratio and texture estimator, and then combine it with the detail layer to get the tone mapped image. To see the difference in contrasts between the original HDR Image and the tone mapped image using our model, we make use of an online dynamic range (in)dependent metric. We present our results and compare it with other tone mapping algorithms and demonstrate that our model is better suited to compress the dynamic range of HDR images preserving visibility and information and with minimal artifacts.

Keywords Computational photography · HDR imaging · Tone mapping

1 Introduction

The perception of real-world scenes by human beings is natural and consists of a wide range of luminance values [1]. HDR Imaging aims to capture all of these luminance values present in the natural scene and can simultaneously incorporate detailed information present in the deepest of shadows and brightest of light sources ([2, 3]). But the range of luminance values that a given display device can reproduce is limited. For instance, only 8 bits (256 levels) of brightness information per channel is assigned for every pixel in video cameras or digital still cameras [4]. This is

A. Gadi Patil (✉) · S. Raman
Electrical Engineering, Indian Institute of Technology, Gandhinagar, India
e-mail: akshay.patil@iitgn.ac.in

S. Raman
e-mail: shanmuga@iitgn.ac.in

B. Raman et al. (eds.), *Proceedings of International Conference on Computer Vision and Image Processing*, Advances in Intelligent Systems and Computing 459,
DOI 10.1007/978-981-10-2104-6_40

because the display devices can reproduce luminance range of about 100:1 Candela per square meter (Cd/m^2) as opposed to human vision which ranges from 100 000 000:1 [5]. In today's world most applications in gaming industry, augmented reality, and photography require that the display devices mimic the images with real-world scene luminance to provide a more realistic and natural experience ([6, 7]). Tone mapping operators (TMOs) aim at maintaining the overall contrast and brightness levels imitating images with high-dynamic range (HDR). Myszkowski in [8] confronts incompatibility between images and display devices while performing dynamic range compression. One of the important aspects of tone mapping is that the same HDR image can be tone mapped into different styles depending upon the situational or contextual considerations [9].

Most often texture, contrast, and brightness information is lost in the process of tone mapping. The relative amount of information of the above-mentioned features is one of the parameters used to measure the quality of the tone mapped image. We propose a novel approach for tone mapping using a computationally efficient texture and brightness estimator which makes use of the local variations in the given HDR image. Variation in the texture information is captured by this texture estimator whereas the relative local brightness information is captured by the brightness estimator. Using this we work on the luminance channel of the HDR image and try to obtain a tone mapped image that leads to same response in the observer as that of a real world scene.

The main contributions of this paper are listed below.

1. Our proposed model uses texture and brightness estimator that is computationally simple compared to most of the existing tone mapping algorithms.
2. A novel framework for preserving contrast and brightness information from HDR to tone mapped images.
3. This approach for tone mapping is an local adaptation that does not affect other similar regions present in the image.

We discuss the existing tone mapping algorithms in Sect. 2. In Sect. 3, we describe the algorithm of the proposed approach. We then present our results in Sect. 4 and compare them with the results of other tone mapping algorithms using the online dynamic range (in)dependent metric assessment [10]. We end the paper with conclusions, discussions and scope for future work in Sect. 5.

2 Related Work

The earliest works on tone mapping were by Tumblin and Rushmeier [11] where they developed nonlinear global mapping functions that characterized the human visual system's brightness and contrast perception. In [12], Ward made use of a simple linear function relating the world luminance and the display luminance using a proportionality constant known as scale factor. Larson et al in [1] used histogram equalization technique which disregarded empty portions of the histogram and was able to achieve efficient contrast reduction. But contrast reduction was not achieved when input image exhibited a uniform histogram. The past decade has seen considerable work deriving motivation from the above ideas and much attention has been given to the tone mapping algorithms since then. Almost all tone mapping algorithms work on the luminance channel of the HDR Image and then integrate this modified luminance channel to the CIE_Lab color space from which the tone mapped RGB image is obtained. Fattal et al. described that large changes in gradients are due to abrupt change in luminance values in HDR images [13]. So large gradients were attenuated keeping the smaller ones unaltered.

The tone mapping methods used can be broadly classified into two groups. The first one is the *spatially uniform* group where in a global mapping function is used that does not account for local variations in the image. It means that a single function is used for all the pixels in the image and usually the global mapping functions are sigmoid or close to sigmoid in nature that preserve some details in highlights and shadows [7]. Because of this, the mapping functions in this group do not directly address contrast reduction. Intuitively this must be computationally inexpensive and the experiments have proven so. The second one is the *spatially varying* group which is local in the sense that mapping functions are applied over a given neighborhood of a pixel just as human vision is sensitive to local contrasts. Some of these operators take motivation from what McCann suggests in [14], lightness perception. The operators presented in ([13, 15, 16]), on the other hand, compute the arithmetic mean of luminance values in a pixel neighborhood. Color is treated as a separate entity by these tone mapping operators [17]. Mantiuk et al. in [18] proposed post processing techniques to reduce color saturation. Durand and Dorsey [16] employed edge preserving smoothing operators to justify locally adaptive processes which help in minimizing haloing artifacts. We base our approach on the one suggested by Ashikmin in [19] by making use of ratio of Gaussian filtered images to get the texture information. We select same kernel size for Gaussian filters in our approach. Due to the localization of the approach, these methods tend to be computationally expensive than spatially uniform or global methods.

Other distinctions among tone mapping operators exist, such as *static* and *dynamic operators*. Our approach falls in the *static operator* category where we work on static images unlike *dynamic operators* which process a stream of images. Information on making use of texture for capturing the details in images is given in Tao et al. [20]. So we derive our motivation from the above and would like to use local features, such as contrast, texture and brightness for tone mapping but at the same time, we want our algorithm to be of same computational complexity as that of spatially uniform methods. Making use of local features will allow us to capture more information that can be used appropriately on display devices than the global compression techniques that store information which produce not so realistic images. It is necessary to preserve every line or edge and every minute detail of the HDR image. Such textures on images can be visibly affected by geometric, radiometric and other distortion as mentioned in [21]. We make use of what Durand and Dorsey suggested in [16], the base layer and the detail layer obtained by splitting a HDR image into two layers using a bilateral filter. In our approach, the detail layer is not processed and only the base layer is processed to compress the dynamic range. We also process only the luminance component of the HDR image while leaving the color components unaltered.

3 Proposed Approach

The block diagram in Fig. 1 explains our methodology of tone mapping. Our proposed approach comprises of four steps for tone mapping of HDR Images. All the four steps are discussed below sequentially.

3.1 Luminance Channel of HDR Image

As mentioned earlier, we work on the luminance channel of the HDR image because the information on the dynamic range of the intensity values is contained in this channel. We extract the luminance channel of the HDR image I using the equation in [22] which is given below.

$$L = 0.2126 I_R + 0.7152 I_G + 0.0722 I_B \tag{1}$$

I_R, I_G, and I_B are the red, green, and blue channels of the image I, respectively. The above equation is used because it closely relates to the human vision perception. Similarly 'a' and 'b' channels are computed and stored unaltered. Once the

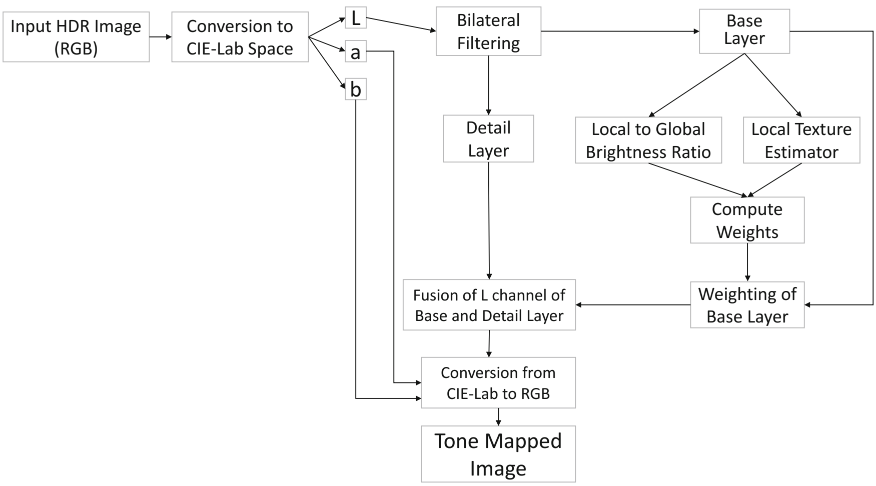

Fig. 1 Block diagram of the proposed approach

luminance channel is obtained, we would like to split it into two layers using bilateral filter. The two layers are: *base layer* and *detail layer*. We work only on the base layer and keep the detail layer as it is.

3.2 Bilateral Filtering

Once the luminance channel of the HDR image is available, we process it using an edge preserving bilateral filter as suggested by Durand and Dorsey in [16]. The output of the bilateral filter gives two layers, the base layer *BL* and the detail layer *DL*. We preprocess the base layer *BL* to extract the texture and brightness information.

3.3 Pre-processing of Base Layer

Once the base layer *BL* is obtained, it is preprocessed to obtain information about texture and brightness as explained below. We compute the weights from local texture estimator and local to global brightness ratio. The base layer is modified by these weights as explained by Eq. (3).

Local Texture Estimation The amount of local texture present is estimated by taking the ratio of local smoothing around a pixel (x, y) of the image I using gaussians of different standard deviations. In the numerator, we use a Gaussian filter $G_{\sigma 1}(x, y)$ of size 9×9 with a standard deviation 1 around that neighborhood of the pixel and we use another Gaussian $G_{\sigma 2}(x, y)$ with a standard deviation of 4. This quantity we call, the texture estimator *T(x,y)*. The equation for the texture estimator is given below.

$$T(x, y) = \frac{G_{\sigma 1}(x, y) \otimes ||g(x, y)||}{G_{\sigma 2}(x, y) \otimes ||g(x, y)||} \tag{2}$$

Here $g(x, y)$ is the gradient around the 9×9 neighborhood of a pixel (x, y) of the base layer *BL* obtained after applying the bilateral filter on the HDR image [20]. We next focus on preserving the brightness in the tone mapped image.

Local Brightness Estimation In the process of tone mapping, the brightness may often get reduced perhaps making the tone mapped image dark. In order to preserve the brightness in the process, we first estimate the average brightness in the neighborhood of a pixel (x, y) and then, we find the average brightness of the entire image. We call Brightness estimator $B(x, y)$, which is the ratio of average local brightness in the neighborhood of a pixel to that of the global average brightness value.

Weighting the Base Layer Now once we have the local texture $T(x, y)$ and brightness $B(x, y)$ estimators, we take a linear combination of these two in accordance with the equation (3) below to compute the weights W and then we weight the base layer and modify it using Eq. (4) given below.

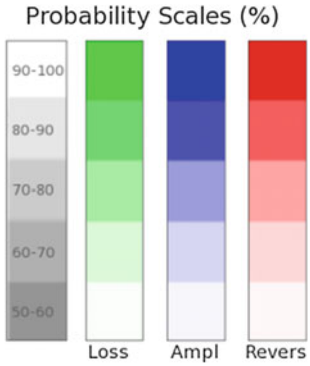

Fig. 2 Dynamic range (in)dependent metric legends [10]

$$W = (\alpha \times T(x, y)) + ((1 - \alpha) \times (B(x, y))^{\beta}) \tag{3}$$

$$\widehat{BL} = BL \times ((\alpha \times T(x, y)) + ((1 - \alpha) \times (B(x, y))^{\beta})) \tag{4}$$

In the above Eq. (4),the first term inside the brackets works to preserve the contrast and texture information and the second term helps in maintaining the brightness information. In Eq. (4) above, we have used two parameters, α and β. Both of them can be varied by the user. Here α takes care of the overall contrast in the image and β takes care of the brightness in the tone mapped image. For the results presented in this paper we have used $\alpha = 0.3$ and $\beta = 0.4$.

3.4 *Fusion and Tone Mapped Image*

Once the preprocessing is done, we then combine the detail layer *DL* on the processed base layer $\widehat{BL}$, thus bringing back every information present in detail layer *DL* back into the image. We are still in the CIE-Lab space. So to get our tone mapped RGB image, we need to convert the image from CIE-Lab to RGB space. Thus, we obtain the final tone mapped image.

4 Results and Discussion

We present the results for a set of nine HDR images on six different state-of-the-art tone mapping methods including the proposed approach which are presented from top row to the bottom row of Fig. 3. The rows are in the order, namely: AdobeLobby, Backyard, diffuse_map, elephant_ fg, face_ fg, puma_ fg, ostrich_fg, smallOffice, and tahoe1 [6]. For every image, we compare our tone mapped image with reference to other standard tone mapping methods. For the results of other tone mapping algorithms, we have used the best possible values of user input parameters. As could be seen from Fig. 3, ChiuTMO gives a blurred image that is not at all appealing and has spilling across edges [6]. TumblinRushmeierTMO increases the brightness in the resulting image and gives good results [11]. FattalTMO gives a dull image with reduced brightness and more dark regions in shadows [13]. WardHistTMO works well but amplifies much of the invisible contrast in the image irrespective of the environment [12]. ReinhardTMO is found to work better only in good lighting ambiance [7]. Our proposed approach better preserves the texture information in all types of environment and closely matches the best among all the other TMOs which is TumblinRushmeierTMO as could be seen from Fig. 4. Since our method uses gradients around a neighborhood of a pixel to estimate texture information and averaging to get brightness, sudden changes in lighting conditions in the image may result in very minute loss of aesthetic appeal but our method is simple and effective. As mentioned earlier, we make use of an online metric to check the quality of our tone mapped image. In order to compare our approach with the other approaches, we present the results of the dynamic range (in)dependent quality metric in Fig. 4 for all the set of images shown in Fig. 3 [10]. This shows that the proposed approach leads to very less distortion in the final tone mapped images. The color codes for various errors can be seen in Fig. 2.

We performed the experiments in MATLAB environment on a laptop that runs 64 bit Windows 7 and has Intel core i5 (1.7 GHz) processor with 6 GB RAM. From Figs. 3 and 4, we see that our proposed TMO is better than ChiuTMO in terms of overall appearance, FattalTMO, ReinhardTMO and WardHist in terms of visibility, WardHistTMO in terms of non-amplification of invisible contrast and gives real-world HDR like image in comparison with all TMOs while closely matching TumblinRushemeirTMO in terms of maintaining the actual contrast.

5 Conclusion and Future Work

The proposed approach tone maps HDR images based on the local texture and brightness cues. The motivation behind using this technique is its simplicity to produce high-quality tone mapped images. Our approach takes only two parameters as input from the user unlike the other TMO's that require three to four parameters on an average. The proposed approach keeps the details intact of the bright and dark regions in the HDR image in the process. Future scope involves subjective studies of tone mapped images instead of using an online dynamic metric to compare the visual perception and aesthetic appeal of our tone mapped images. Based on the descriptions of the images given by the subjects we would like to work on improving our approach in comparison to other TMOs if the subjects feel a big difference in the quality of the tone mapped images.

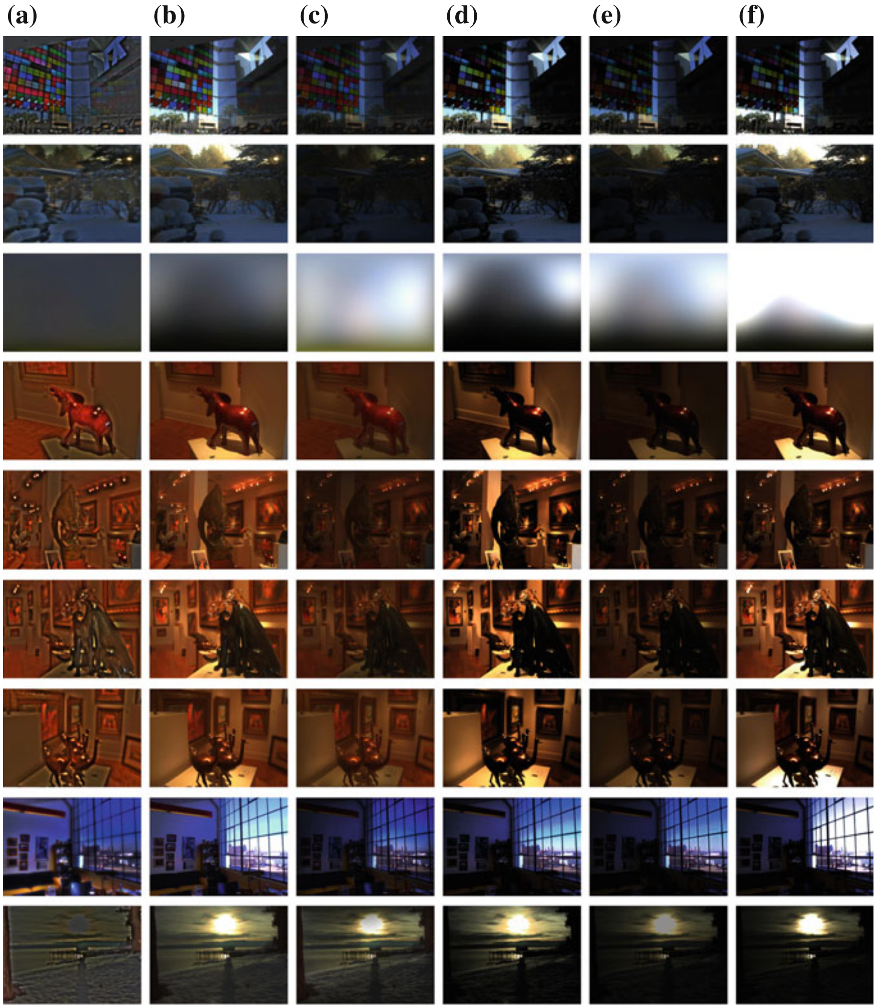

Fig. 3 Tone mapped images for different methods: **a** ChiuTMO [6], **b** TumblinRushmeierTMO [11], **c** FattalTMO [13], **d** WardHistTMO ([1, 12]) **e** ReinhardTMO [23], **f** Proposed TMO

Fig. 4 Dynamic range (in)dependent metric comparison for **a** ChiuTMO [6], **b** TumblinRushmeierTMO [11], **c** FattalTMO [13], **d** WardHistTMO ([1, 12]) **e** ReinhardTMO [23], **f** Proposed TMO.The corresponding color code is shown in Fig. 2

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