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A Brief Learning of Various Tone Mapping Operators for High Dynamic Range Images

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ABSTRACT

Background: Visualization of HDR images on standard LDR Displays, Tone mapping Operators **(**TMO) provide useful tools as convertors to convert high dynamic range images to Low dynamic range image**.** The high Quality tone mapping technique is what is used to display the high contrast image on devices with limited dynamic range of luminance values. To improve the contrast in dark areas, changes has to be done to the gamma correction procedure which improves the quality of the images while visualized in the LDR device. **Objective:** This paper demonstrates the study of various tone mapping operators for both still images and video. **Results:** The temporal artifacts such as flickering and goasting are exemplified in video processing by applying the appropriate tone mapping operator. **Conclusion:** This paper explores the various methods available for still and video.

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INTRODUCTION

In the recent times, the trend in imaging is towards producing and using the High resolution images. Although the trend is majority towards high resolution image, that are apparent, we are at the dawn of major shift in thinking about digital images, which pertains to the range of values of each pixels which represents the image and the size. In recent scenario the colour images are represented with byte per pixels for each images of red green and blue channels, i.e. RGB shades. Even after stating that there are only 256 values of each red green and blue components of each pixel, 1.6million colours can be assigned .Hence, the HDR imaging is a technique used in imaging and photography to reproduce a greater dynamic range of luminosity than the usual standard photographic techniques. The low dynamic range images are converted to high resolution by HDR Imaging technique. This is done with the help of radiance mapping which results in High Dynamic Range Images. The HDR images is very promising and the quality is much higher than with the conventional imagery. Generally HRD images have high range of luminance levels found in real–world scenes from direct sunlight to faint nebula. The technique used in high Dynamic range imaging and photography is to reproduce a greater dynamic range of luminosity than the usual standard photographic. The Radiance mapping plays a vital role in generating the low dynamic range images to high resolution. As compared to the conventional imagery, the fidelity of the HDR images is much higher than other images. In broad, the HRD images have high range of luminance levels found in real–world scenes from direct sunlight to faint nebula. HDR image is obtained by the fusion of multiple exposures of the single image. By and large the photographs taken in Mann (1993), Mann and Picard (2007), Kaufmann *et al*. (2005), Banterle *et al*. (2011). Non-HDR cameras will have got exposed to very limited range, hence resulting in the loss of details in bright or dark areas. Alternately, compensation to the loss of details are carried by capturing multiple photographs at different exposure levels and combining them to produce a photograph representative of a broader tonal range. The HDR images can be classified with respect to computer renderings by merging multiple low-dynamic-range (LDR) (Gortler *et al*. 2001) or standard-dynamic-range (SDR) (Mery and Rued, 2007) photographs. These images can be acquired by using Special image sensors like oversampled binary image sensor. To produce images with preserved or exaggerated local contrast for artistic effect different Tone mapping methods are available, which reduces overall contrast to facilitate display of HDR images on devices with lower dynamic range.

There are developed versions of the HDR monitors developed. Some of the developed HDR monitors in the recent times enable the display of HDR images with hardly any compression of their dynamic range. The newly developed displays that has arrived in the market demands new tone mapping algorithms. Generally the increase

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in the dynamic range is an advantage while mapping the SDR to HDR display devices by re-rendering. While converting the SDR to HDR the operation could be reversed. Natural scenes can have a wide range of illumination conditions, ranging from night scenes to outdoor scenes. Examples of scenes and corresponding maximum luminance are given in Figure. 1 (Johnson, 2005). For us to "see" all these different scenes and form a percept where details are visible, our visual system adapts to the illumination conditions in different ways (Webster, 1996, Pattanaik *et al*. 1998). A first adaptation to global illumination takes place at the pupil, which changes its diameter depending on the amount of light entering the eye. Second, the photoreceptors (cones) adapt their sensitivities to the mean luminance in the field of view, given by total retinal illumination. Third, local adaptation modulates local contrasts as our gaze visually scans the scene.

Fig. 1: Maximum luminance values for various scenes.

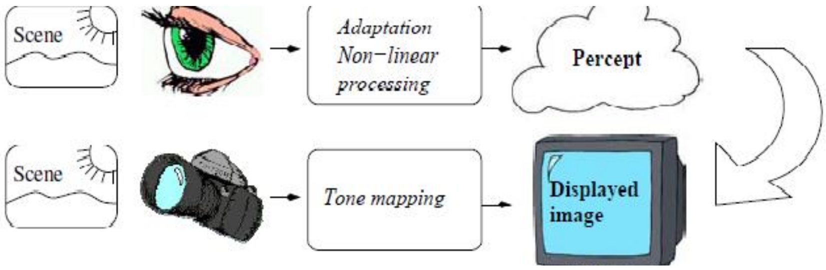

Fig. 2: The processing of HSV.

Capturing devices can display the image with flare correction and approximate radiances. So one of the important task of the camera is to simulate the processing of the HVS and to make its representation more perceptually as shown in Figure 2 shows the HSV processes of the scene with different adaption processes.

Classification of Tone Mapping Operator:

Tone mapping operators are designed in such a way that they reproduce visibility and the overall impression of radiance and visibility a contrast and color of the real world onto limited dynamic range output devices. The image can be represented by the three basic colour channels called red (R), green (G), blue (B) simply as RGB image. Tone mapping can be applied to the three color channels independently by performing the same operation three times. This is commonly used for global tone mapping and provides good color rendition. However, with local tone mapping, treating the R, G, B color channels independently may lead to bad color rendition. Another way of applying a tone mapping algorithm to a color image is to transform the RGB image into a luminance/chrominance representation where the achromatic and chromatic information are separated, and to process the achromatic channel only. The luminance/chrominance image is composed of one luminance channel containing the achromatic information and two chrominance channels containing the color information. Figure 3 shows the maximum luminance values for various scenes.The chrominance channels are often encoded with opponent colours (i.e. red-green and yellow-blue). In this context, the word luminance is different from the physical quantity that we introduced earlier. It refers to the achromatic content of the image and can represent the perceived values if a non-linearity has been applied. Because it is often called "lumi-nance" in the literature.

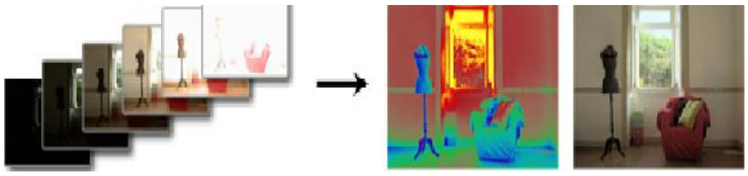

Fig. 3: Maximum Luminance values for various scenes.This figure was taken from (Johnson2005).

In general, these transforms are applied to non-linear RGB. The color transforms to decorrelate the color channels and process the luminance only. Several color transforms have been standardized for different purposes. For example, YUV, YIQ, YCrCb (Poynton, 2003) are used in the television broad- casting system and compression. CIE Lab, CIE Luv are used in colorimetry to define perceptually uniform color spaces for color difference evaluation (CIE 15:2004). Generally the tone mapping operator can be classified as global and the local operators based on their representations given as in the Table 1.

Global Tone Mapping Operators:

Tone mapping approach and the exposure fusion are two methods to combine multiple exposed images in to a single image, of which exposure fusion is the recent one. They produce better results though both have their own advantages and differences in their approach. Tumblin and Rushmeier (1993) introduced the first concept as tone mapping (Tumblin and Rushmeier, 1993). The goal of tone reproduction is to compress the dynamic range of an image to the range that can be displayed on physical devices in case that the luminance range of the images is much broader than that of physical devices. A number of tone mapping techniques have been presented, and most of them can be categorized into two groups: global and local operators. Figure 4 represents the classification of tone mapping operators.Global operators apply the same transformation to every pixel of an image while local ones adapt their scales to different areas of an image. The existing tone mapping operators are summarized in a recent review by Pattanaik *et al*. (2000). The global operators are the linear mapping and the methods of Pattanaik *et al*. (2000), Larson *et al*. (1997) and Drago *et al*. (2003). The local operators are the fast bilateral filtering presented by Durand and Dorsey (2002), Ashikhmin *et al*. (2002), and Reinhard *et al*. (2002) methods.

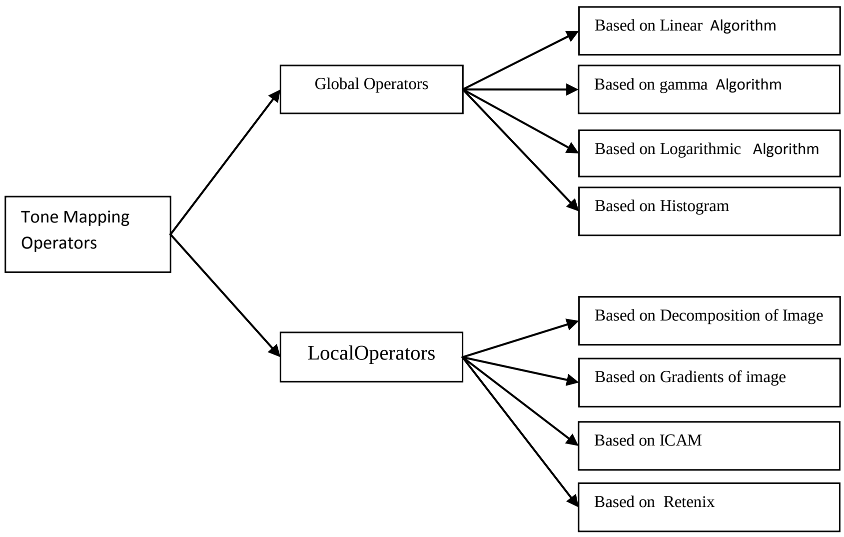

Fig. 4: Classification of Tone Mapping Operators.

The simplest tone reproduction is a linear mapping which scales the radiances to the range between 0 and 255. If the logarithm of the radiances is taken and linearly scaled to [0, 255], it is called a logarithmic linear mapping. The histogram adjustment tone mapping operator developed by Larson *et al*. (1997) builds on earlier work (Ferwerda *et al*., 1996, Ward, 1994). The algorithm features strong contrast compression for pixels belonging to sparsely populated regions in the image histogram, which helps to overcome the problem of dynamic range shortage. This method leads to a monotonic tone reconstruction curve which is applied globally to all pixels in the image. The slope of the curve is constrained by considering the human contrast sensitivity to guarantee that the displayed image does not exhibit more contrast than what is perceived in the real scene. Pattanaik *et al*. extended the perceptual models framework by Tumblin and Rushmeier (1993) and presented a new time- dependent tone mapping operator which is based on psychophysical experiments and a photoreceptor model for luminance values (Pattanaik *et al*., 2000). This algorithm deals with the threshold visibility changes, appearance in color, acuity in visual system, and sensitivity. The visual adaptation model and the visual appearance model are the two models in which this algorithm can briefly be decomposed into. The signals that simulate the adaptation measured in the retina are used for adaptation in each pixel of an image. To reproduce visual appearance, it is assumed that a viewer determines reference white and reference black colours. Then, these reference points are the basis for the calculation of the visual appearance with values. By assembling those visual adaptation and appearance models, the scene appearance is reproduced with changes to visual adaptation depending on time. This method is also useful to predict the visibility and appearance of scene features because it deals with reference white and black points. Adaptive logarithmic mapping (Ward *et al*., 1997, Drago

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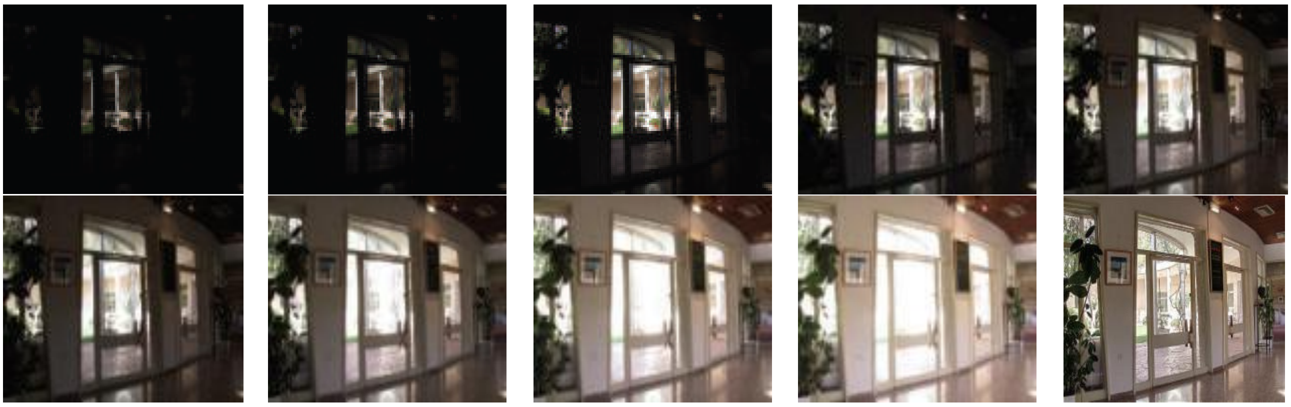
et al., 2003) was hence a method introduced by Drago *et al*. (2003). This method addresses the need for a fast algorithm suitable for interactive applications which automatically produces realistically looking images for a wide variation of scenes exhibiting high dynamic range of luminance. This global tone mapping function is based on logarithmic compression of luminance. To preserve details while providing high contrast compression, a family of logarithmic functions ranging from $\log_2$ to $\log_{10}$ with increasing compressive power are used (Perlin and Halo, 1989). The $\log_{10}$ is applied for the brightest image pixel and for remaining pixels the logarithm base is smoothly interpolated between values 2–10 as a function of their luminance. Perlin bias power function (Perlin and Halo, 1989) is used for interpolation between the logarithm bases to provide better steepness control of the resulting tone mapping curve.



Multiple Exposure images (input)

Ward *et al*. (1997) Ashikhmin *et al*. (2002) Reinhard *et al*. (2002) Durand and Dorsey (2002)

Fig. 5: Example of Tone Mapping Operators (both Global and Local).

Local Operators:

Reinhard *et al*. presented a photographic tone reproduction inspired by photographic film development and the printing process (Reinhard *et al*., 2002). Figure5 shows the results of various local and global operators.The luminance of an image is initially mapped by using a global tone mapping function to compress the range of luminance into the displayable range. To enhance the quality of an image, a local adaptation is based on photographic "dodging and burning" technique which allows a different exposure for each part of the applied image. The most recent version of this method operates automatically, freeing the user from setting parameters (Reinhard, 2003). To automate processes, low contrast regions are found by a centre-surround function at different scales. Then, a tone mapping function is locally applied. The automatic dodging and burning method enhances contrast and details in an image while preserving the overall luminance characteristics. A new tone mapping method was presented by Ashikhmin which works on a multipass approach (Ashikhminn, 2002). The method takes into account two basic characteristics of the human visual systems (HVS): signalling absolute brightness and local contrast. This method first calculates local adaptation luminance by calculating an average luminance of neighbouring pixels fitting in a bound-limited contrast range (similar to Reinhard *et al*., 2002). Then, it applies the capacity function which is based on the linearly approximated threshold vs. intensity function and calculates the final pixel values. The final calculation restores the details which may be lost in the steps of compression. A tone mapped pixel value is obtained by multiplying a detail image given by the ratio of pixel luminance to the corresponding local world adaptation. A fast bilateral filtering method was presented by Durand and Dorsey (2002). This method considers two different spatial frequency layers: a base layer and a detail layer. The base layer preserves high contrast edges and removes high-spatial frequency details of lower contrast. The detail layer is created as the difference of the original image and the base layer in logarithmic scale. After contrast compression in the base layer, both layers are summed up to create a tone mapped image. Some of the example tone mapped operator results are given below.

Steps Involved in Tone Mapping:

Hollow artefacts and greying out are some of the issues in HDR image rendering. There is a compromise between the increase in the local contrast and rendition of image. The increase in local contrast leads to artefacts whereas a week increase in local contrast does not provide detail visibility. These issues are addressed by local and global tone mapping methods. The gamma correction (global tone mapping), Reinhahard's (local tone mapping methods presents the image fusion which results in the enhancement of contrast, saturation and luminance method with scalar weight map. Steps involved in tone mapping include about 10 steps. Each step plays a vital role. The given input is a linear RGB value of radiance of the input image. The intensity is calculated by averaging the color channels and then the required filter is applied in order to segregate detail and base layer. Once the detailed layer is computed, the normalization procedure is carried out following which the reconstruction of image takes place. This is done by combining the detail and base layer by Gaussian or Laplacian pyramids. Though the filter operates with a common procedure, the kernel design of the filter applied is different for each tone mapping operator used.

Tone Mapping for Video:

One of the main challenges in high-dynamic-range (HDR) imaging and video is mapping the dynamic range of the HDR image to the much lower dynamic range of a display device. While an HDR image captured in a high contrast real-life scene often exhibits a dynamic range in the order of 5 to 10 $\log_{10}$ units, a conventional display system is limited to a dynamic range in the order of 2 to 4 $\log_{10}$ units. Most display systems are also limited to quantized 8-bit input. The mapping of pixel values from an HDR image or video sequence to the display system is called tone mapping, and is carried out using a tone mapping operator (TMO) (Pattanaik *et al.*, 2000). Eleven tone-mapping operators intended for video processing was taken into account for writing this paper.

While designing the tone mapping operator the following details has to be considered:

- Temporal model free from artifacts such as flickering, ghosting and disturbing temporal color changes.
- Local processing to achieve sufficient dynamic range compression in all circumstances while maintaining a good level of detail and contrast.
- An Efficient algorithms, is essential Turnaround time should be kept as short as possible since the large amount of data is used.
- parameter tuning is not necessary
- Calibration of input data should be kept to a minimum, e.g. without the need of considering scaling of data.
- Capability of generating high quality results for a wide range of video inputs with highly different characteristics.
- Explicit treatment of noise and color.

Table 1: Represents the list of tone mapping operators for video processing. Processing refers to either global processing that is identical for all the pixels within a frame or local processing that may vary spatially.

Operator	Processing	Intent	Description
Visual adaptation TMO (Pattanaik *et al*., 1996)	Global	VSS	Threshold visibility Visual response model is based on measurements of threshold visibility as in [War94].Use of data from psychophysical experiments to simulate adaptation over time, and effects such as color appearance and visual acuity.
Time-adaptation TMO (Pattanaik *et al*., 2000)	Global	VSS	Based on published psychophysical measurements [Hun95]. Static responses are modeled separately for cones and rods, and complemented with exponential smoothing filters to simulate adaptation in the temporal domain. A simple appearance model is also included.
Local adaptation TMO (Ledda *et al*., 2004)	local	VSS	Temporal adaptation model based on experimental data operating on a local level using bilateral filtering.
Mal-adaptation TMO (Irawan, 2005)	Global	VSS	Based on the work by Ward *et al*. [WLRP97] for tone mapping and Pattanaik *et al*. [PTYG00] for adaptation over time. Also extends the threshold visibility concepts to include mal adaptation.
Virtual exposures TMO (Bennett and Macmillan, 2005)	Local	BSQ	Bilateral filter applied both spatially for local processing, and separately in time domain for temporal coherence
Cone model TMO (Van Hateren, 2006)	Global	VSS	Dynamic system modeling the cones in the human visual system over time. A quantitative model of primate cones is utilized, based on actual retina measurements.
Display adaptive TMO (Mantiuk *et al*., 2008)	Global	SRP	Display adaptive tone mapping, where the goal is to preserve the contrasts within the input (HDR) as close as possible given the characteristic of an output display. Temporal variations are handled through a filtering procedure.
Retina model TMO (Benoit *et al*., 2009)	local	VSS	Biological retina model where the time domain is used in a spatio-temporal filtering for local adaptation levels. The spatio-temporal filtering, simulating the cellular interactions, yields an output with whitened spectra and temporally smoothed for improved temporal stability and for noise reduction

Color appearance TMO (Boitard *et al*., 2012)	local	SRP	Display and environment adapted image appearance calibration, with localized calculations through the median cut algorithm.
Temporal coherence TMO (Ward, 1994)	local	SRP	Post-processing algorithm to ensure temporal stability for static TMOs applied to video sequences. The authors use mainly Reinhard's photographic tone reproduction [RSSF02], for which the algorithm is most developed. Therefore, the version used in this survey is also utilizing this static operator.
Camera TMO (Larson *et al*., 1997)	Global	BSQ	Represents the S-shaped tone curve which is used by most consumer-grade cameras to map the sensor-captured values to the color gamut of a storage format. The curves applied were measured for a Canon 500D DSLR camera, with measurements conducted for each channel separately. To achieve temporal coherence, the exposure settings are anchored to the mean luminance filtered over time with an exponential filter.

GENERAL STEPS INVOLVED IN TONE MAPPING

STEP 1: Input image values are the radiance value of RGB Values..

STEP 2: Intensity (I) of the image is calculated by averaging the color channels.

STEP 3: Chrominance channels should be calculated with (R/I, G/I, B/I)

STEP 4: Log intensity is calculated as L = log2(I)

STEP 5: Apply any filter (eg: bilateral filter) to get the Base layer B = bf(L))

STEP 6: Detail layer has to be computed D = L – B

STEP 7: Apply an offset and a scale to the base: B' = (B - o) * s

7.1 The offset is such that the maximum intensity of the base is 1.

7.2 The scale is set so that the output base which depends on the dR stops of dynamic range, s = dR / (max(B) - min(B)). Try values between 2 and 8 for dR that should cover an interesting range. Values around 4 or 5 should look fine.

STEP 8: Getting back the values reconstruct the clog intensity: O = 2^(B' + D)

STEP 9: The colour should be replaced with new values of: R',G',B' = O * (R/I, G/I, B/I)

STEP 10:Finally gamma compression is calculated, lack gamma compression the result will look too dark. Values around 0.5 would look fine (e.g. result.0.5). Apply the simple global intensity scaling to the final output. The HDR images having zero values which will cause problems with log. This problem can be fixed by replacing all zeros by some non-zero values.

Qualitative Analysis of Various Tone Mapping Operators:

Conclusion:

A brief study of the various operators are given above which helps in identifying the operators according to the need of enhancement. This study helps in discovering the new operator which enables the HDR picture to LDR. A Qualitative analysis of the various operator with the goal of identifying the weakness and strengths are shown in the above table. The temporal artifacts such as flickering and goasting are exemplified in video processing by applying the appropriate tone mapping operator .The steps in tone mapping operating algorithm is now considered in exposure fusion which is very similar to this , is an upcoming field in the research .The exposure fusion is similar to tone mapping where the main difference is that the tone mapping operator

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resultant ant image is an HDR image and the fusion image is LDR image. The future work will be an survey of exposure fusion and the comparison of tone mapping and exposure fusion.

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