Small Area Edge Preservation for Multiscale Decomposition for High Dynamic Range Image Tone Mapping

Yedu Manmadhan, Anto Kumar R.P

Abstract— One of the ultimate aims of image processing is to represent real-world scenes on conventional display devices. For this purpose, image-processing technology has been developing from Standard Definition (SD) to High Definition (HD) in terms of resolution, as well as being developed from the Low Dynamic Range (LDR) of 8-bit data to the High Dynamic Range. Many recent computational photography techniques decompose an image into a piecewise smooth base layer, containing large scale variations in intensity, and a residual detail layer capturing the smaller scale details in the image. In many of these applications, it is important to control the spatial scale of the extracted details, and it is often desirable to manipulate details at multiple scales, while avoiding visual artifacts. In this work a new way to construct edge-preserving multi-scale image decompositions is introduced A novel filter is proposed for edge-preserving decomposition of an image. It is different from previous filters in its locally adaptive property. A multiscale decomposition with this filter is proposed for manipulating a high dynamic range image, which has three detail layers and one base layer. A process is proposed with the novel filter to reproduce HDR images. There is an important property in the decomposition, which is the residual base layer matches the large-scale shape of the original image signal. The tone mapped images using these edge-preserving filters give state-of-the-art quality, and they are visually appealing. Through this reproduction process, we can hardly discern the difference between the artificial image and the real scene. Special considerations are also noted here to avoid artifacts (e.g., halo, the brighter or darker bands around edges).

Keywords: High Dynamic Range, Multiscale Decomposition, Edge Preservation, Tone Mapping, Small Area Edge Preservation

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1. INTRODUCTION

High dynamic range (HDR) images provide superior picture quality by supporting a very large luminance range, which is comparable to what human vision is able to perceive. On the other hand, existing content is considered to be in low dynamic range (LDR), which allows only a limited range of contrast and is far below the capability of human vision. HDR signals are encoded with at least 10 bits per colour channel, as opposed to LDR signals which are represented by only eight bits. Although the majority of today's displays can support only LDR content, they can all provide much better picture quality if the content is first captured in HDR and then converted to LDR format. Such production pipeline, i.e., shooting in HDR and then rendering to LDR, has been increasingly gaining interest in movie/television production and high-end photography[1].

Different approaches have been developed for producing a larger dynamic range. HDR recording was first studied for still image photography where multiple exposures of a static scene are captured and then combined to construct an HDR radiance map [7],[10]. In order to show HDR content on existing/8-bit displays, tone-mapping needs to be conducted to convert the HDR signal to an LDR format. A large variety of tone-mapping operators (TMOs) have been developed for different purposes, ranging from photographic tone reproduction to adaption to different displays [3]. Combining HDR capturing and tone mapping is beneficial even when an LDR display is used because they together produce higher quality images with much less over and under saturated areas compared to the traditional LDR capturing process. In addition, tone-mapping allows higher degrees of freedom for artists who during post production can decide the final effect/style of the resultant LDR image. The proposed work is focusing on the natural rendering of an image for comfortable viewing without any significant artifacts like halo effect.

Many recent computational photography techniques decompose an image into a piecewise smooth base layer, containing large scale variations in intensity, and a residual detail layer capturing the smaller scale details in the image . In many of these applications, it is important to control the spatial scale of the extracted details, and it is often desirable to manipulate details at multiple scales, while avoiding visual artifacts [2] [4].

The literature research survey shows that current base detail decomposition techniques, based on the bilateral filter, are limited in their ability to extract detail at arbitrary scales. Instead, the use of an alternative edge-preserving smoothing operators, based on the weighted least squares optimization framework, which is particularly well suited for progressive coarsening of images and for multi-scale detail extraction is advocated.

Jiang Duan Marco Bressan and Chris Dance (2010) in "Tone-mapping high dynamic range images by novel histogram adjustment" present histogram adjustment methods for displaying high dynamic range image. This method is motivated by the need for fast and automatic tone mapping operators which can effectively and efficiently compress high dynamic range scene to display on low dynamic range devices such that the reproduced images look pleasing and evoke our visual experiences in the original HDR scenes. In this paper, tone mapping for displaying high dynamic range images were studied. Manipulation of image histogram is usually a way to control image contrast. In the work the authors propose a fast global histogram adjustment based tone mapping operator, which effectively utilizes the full dynamic range of display and thus well reproduces global contrast for high dynamic range images. However, this operator cannot better preserve local contrast and details, which is the common draw- back of global tone mapping operators [5].

2. PROPOSED METHOD

Fr´edo Durand et al.(2008) in "Edge-preserving Multiscale Image Decomposition based on Local Extrema proposed a model for detail that inherently captures oscillations, a key property that distinguishes textures from individual edges[8]. Inspired by techniques in empirical data analysis and morphological image analysis, they use the local extrema of the input image to extract information about oscillations: The definition of detail is given as the oscillations between local minima and maxima. Building on the key observation that the spatial scale of oscillations are characterized by the density of local extrema, an algorithm was developed for decomposing images into multiple scales of superposed oscillations. Other edge-preserving image decompositions assume image detail to be low contrast variation. Consequently they apply filters that extract features with increasing contrast as successive layers of detail. As a result, they are unable to distinguish between high contrast, fine-scale features and edges of similar contrast that are to be preserved [8].

2.1. SMALL AREA EDGE PRESERVING FILTER

A novel filter is proposed for edge-preserving decomposition of an image. It is different from previous filters in its locally adaptive property. The filtered image contains local means everywhere and preserves local salient edges. The salient edges are no longer thought of as large gradients of the whole image, and they are locally adaptive. The reason for such a proposed method is that, in high dynamic range images the intensity variations in a very small area will be very high. So such intensity variations should result in a new edge formation. But most of the recent methods filter the edges globally. The inside intensity variations in a given area is not taken into account. In other words, one small gradient may also be an important edge locally. So the definition of salient edge should be changed. The Weighed Least Square filter approach has defined a salient edge as a large gradient globally [11] while we are defining a salient edge as a relatively large gradient locally. Therefore the decomposition process is different in that a locally salient but small gradient will be decomposed into the base layer. The filter is called Small Area Edge Preserving (SAEP) filter, and it will efficiently and effectively produce visually pleasing images.

There are two parameters for SAEP: α and β. They are relevant to the filter's sensitivity to gradient. Alpha (α), balances between the data term and the smoothness term. Increasing α will produce smoother images. Default value 0.1 Beta (β), gives a degree of control over the affinities by non-linearly scaling the gradients. The intensity variation points are taken both in x and y directions of an image. The parameters are applied as per the equations in (1)-(4.) More gradients will be treated as salient edges when α or β *is* small. Otherwise, when α or β is large, the filtered output will be over smoothed (less gradients will be treated as salient edges). The image becomes blurred with the increase of α or β, while the details are kept with the decrease of α or β. The values for α =1 and β = 0.1 is found to always produce satisfactory results, burring details while preserving salient edges.

dy = diff (image, 1, 1) ---(1)
dy = -alpha./(abs(dy).^beta) ---(2)
dx = diff(image, 1, 2) ---(3)
dx = -alpha./(abs(dx).^beta) ---(4)

Figure 1 clearly shows the comparison of the SAEP filter and the weighted least squares filter. The input is a synthetic image. The window radius is set as (if it has) a large value for testing the edge preserving effect. It seems that WLS is the best at smoothing oscillations. Bilateral filter and guided filter are not good at preserving edges. The SAEP seems to find a place between them. It can preserve edges, but the smoothing seems not good as WLS. This is just the feature of the small area edge preserving filter that the local salient edges are preserved in the filtered based layer. The advantage of the SAEP filter is the preserving of local edges. Another advantage of the SAEP is that the algorithm's asymptotic time complexity is independent of the window size.

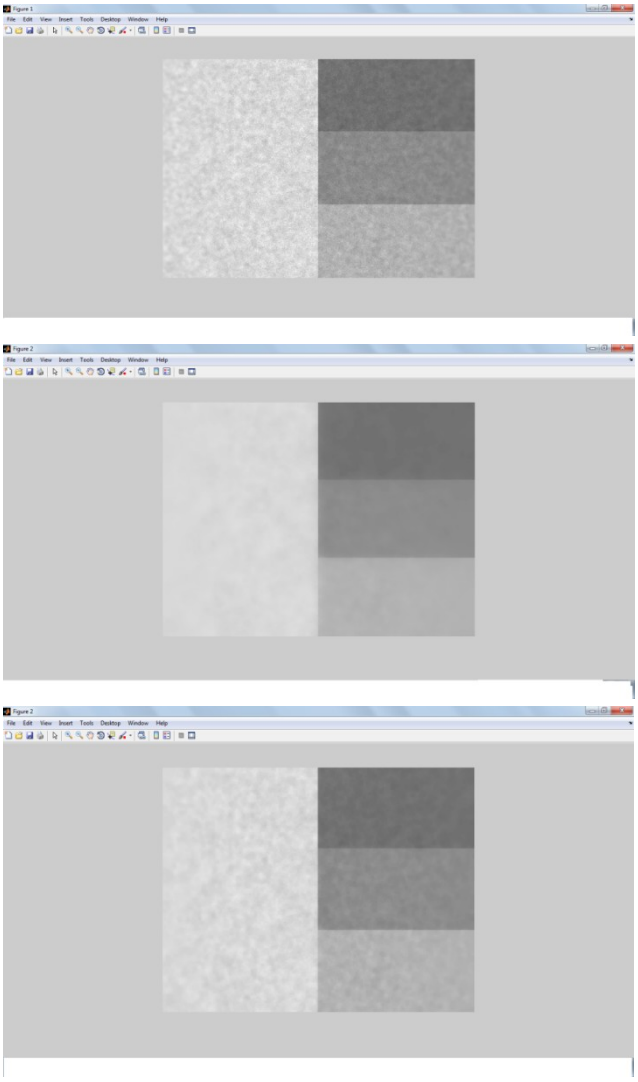


Figure 1: Comparison between SAEP filter and WLS filter .
(a)Synthesized input image
(b)Result of WLS filter
(c)Result of LEP filter

2.2. HDR TONE MAPPING USING SAEP

A novel filter is proposed for edge-preserving decomposition of an image. It is different from previous filters in its locally adaptive property. The filtered image contains local means everywhere and preserves local salient edges. A multiscale decomposition with this filter can be done for manipulating a high dynamic range image, which has three detail layers and one base layer. Edge-preserving becomes an important property in filtering design to avoid halo artifacts. This technique decomposes an image into a piecewise smooth base layer and a detail layer. The base layer no longer only contains low frequency band, but it also has salient edges (high frequency). Multi-scale is used here to decompose progressively another detail layer from the last decomposed base layer. In other words, the high-frequency information is progressively decomposed from the original image. There is an important property in the decomposition, which is the residual base layer matches the large-scale shape of the original image signal. The tone mapped images using these edge-preserving filters give state-of-the-art quality, and they are visually appealing.

In this work, the high quality of compressed HDR images is pursued. The compressed images will be effective for ordinary displaying and printing. The algorithm proposed will be very efficient that it is capable to process high-resolution images. Another objective is that no significant artifacts should be visible in the image. Modern cameras are unable to capture the full dynamic range of commonly encountered real-world scenes. In some scenes, even the best possible photograph will be partially under or over-exposed. Researchers and photographers commonly get around this limitation by combining information from multiple exposures of the same scene. Software can be implemented to automatically combine multiple exposures into a single high dynamic range radiance map, and then convert this radiance map to an image suitable for display through tone mapping which uses the small area edge preserving filter that has been experimented in the former section.

The work is following the idea that an image can be decomposed into a base layer and a detail layer. The base layer is assumed to preserve local means, and then the details are oscillations around zero. Since it is hard to discern which gradient information belongs to base layer and, which belongs to detail layer, the assumption is that all the nonzero gradient information belongs to the detail layer. The base layer only contains zero gradient information. These assumptions seem useless, because a single decomposition makes no difference to the original image. As a result, a multi-scale decomposition is applied. That is an image can be decomposed into a base layer and multiple detail layers:

$$I = B + DL1 + DL2 + DL3$$

The base layer B is plain with no gradient, and the cumulative sum of base layer and detail layers is the next scale's base layer, which contains the salient edges and the local means everywhere.

A single SAEP operating on original image will give a base layer and a detail layer. The base layer preserves local means and local salient edges. The detail layer contains oscillating signal around zero. Iteratively applying SAEP to the base layer will generate a multi-scale decomposition. While iterating, the local window is increasing, which results in progressive coarsening.

In the proposed method, every image is to be decomposed into three detail layers and one base layer. It is researched that this decomposition style addresses a basic idea that one decomposition for fine scale, one for the medium scale, and one for the whole image's scale[8]. The process is that the salient edges are progressively decomposed into detail layers.

Thus the proposed system algorithm in **figure 2** is as explained here. The input HDR radiance map has to be transformed into a HSV colour model. We get the luminance simply by averaging the three channels. And then the luminance is transformed into its logarithm domain. This is a typical operation of most methods. The logarithm of luminance approximates the perceived lightness. To sufficiently use the domain of the logarithm function, we need to arbitrarily magnify the luminance 10^6 times. Finally, the gray image is found by scaling L into range [0, 1]. Another special operation is after the dynamic range compression. Since we have arbitrarily used the mean after twice iterative decompositions to give the last base layer, the last found detail layer may bears high dynamic range, and we have to divide it by two to halve its range. Then after recombining all the layers with the needed gain the RGB colour can be restored back. The output will be a more appealing high dynamic range images.

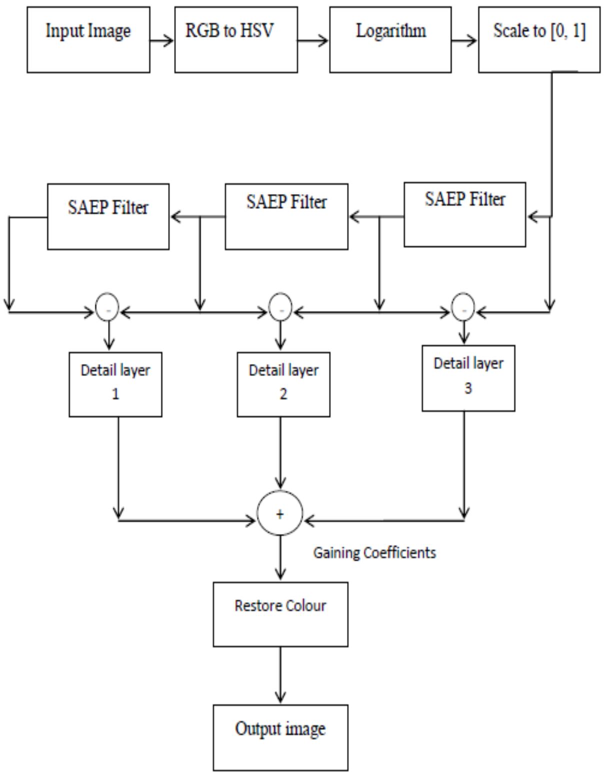


Figure 2: SAEP HDR Tone mapping block diagram

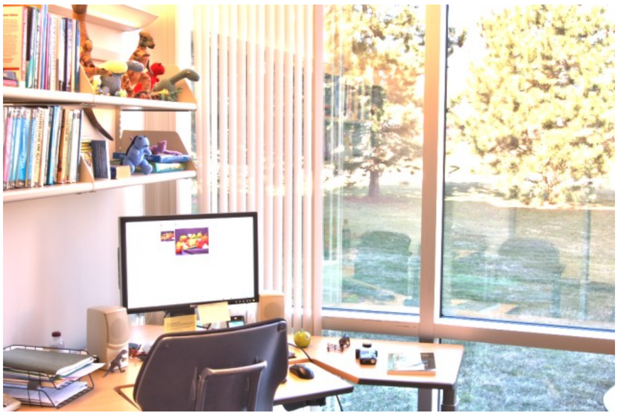
The steps of HDR tone mapping with SAEP filter is as follows:

i. Read HDR image
ii. Change the input image to double precision of HDR image
iii. Convert the RGB image to HSV colour model
iv. Compute the intensity (I) by averaging the colour channels.
v. Compute the log intensity: L = log2(I)
vi. Scale the image in the range [0,1]
vii. Filter the base layer with a SAEP filter
viii. Find the detail layer using D = L - B
ix. Repeat the filtering to find 3 detail layers
x. Apply the gaining coefficients to each detail layers
xi. Reconstruct the log intensity
xii. Put back the colours and output image is obtained

3. EXPERIMENTAL RESULTS

Comparison of the reproduced HDR images obtained by the same process but using different filters SAEP and WLS is shown in figure 3. The WLS filter is a global optimizer while our SAEP filter is locally adaptive. The image of (a) seems clearer than that of (b). In the close-ups, the lines of codes on the bright screen and the thin tree branches over the bright blue sky can be discerned more easily in (a) than that in (b). The SAEP result preserves details everywhere and looks natural and clean globally.

(a)



(b)

Figure3: Comparison between our method (a) and WLS method(b)

The output image seen using WLS method lacks in the sharpness and naturality when compared with the original image. The decompositions which is based on a Small Area Edge Preservation filter method, as demonstrated on figure 3(a), does not suffer from some of the drawbacks of WLS method,bilateral filtering and other previous approaches. In particular, SAEP allows small features to gracefully fade in magnitude, so that they do not persist into coarse levels, but without introducing significant blurring, which can result in halos when differences are magnified.

The implemented Matlab codes take about 2 seconds on a HP laptop with Intel Core i5 3.4 GHz CPU and RAM 4GB for processing a megapixel image.

4. CONCLUSION

The attempt to reproduce the visual perception of the real world is at the heart of painting and photography. Artists have long been endeavoring to develop skills in simulating actual reflected light within the limitation of the medium, since our world generally delivers a much wider range of luminance than pigments can reflect. Apart from artistic concern, recreating real-scene impressions on limited media is also inevitable in many vision and graphics applications

The compression is based on the feature of the human visual system (HVS) that it is less sensitive to the low-frequency components than to the high frequency components. The low-frequency components are compressed while the high-frequency components are retained. Through this reproduction process, we can hardly discern the difference between the artificial image and the real scene. Special considerations are also noted here to avoid artifacts (e.g., halo, the brighter or darker bands around edges).

Edge-preserving becomes an important property in filtering design to avoid halo artifacts. This technique decomposes an image into a piecewise smooth base layer and a detail layer. The base layer no longer only contains low frequency band, but it also has salient edges (high frequency). Multi-scale can be used here to decompose progressively another detail layer from the last decomposed base layer. In other words, the high-frequency information is can be progressively decomposed from the original image. There is an important property in the decomposition, which is the residual base layer matches the large-scale shape of the original image signal. The tone mapped images using these edge-preserving filters give state-of-the-art quality, and they will be visually appealing.

The new algorithm will be aiming to enhance contrast, local detail, colour reproduction, and removal of artifacts. The method is also focusing on the natural rendering of an image for comfortable viewing.

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