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Enhanced Tonemapping Using LEP Filter, Multiscale Decomposition and Noise Reduction

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Abstract

A filter that does edge-preserving decomposition of an image is implemented here. It is containing the Local Edge Preserving (LEP) filter which has locally adaptive property. The filtered image contains local means everywhere and preserves local salient edges. Analysis has been done on the output of the method. A multiscale decomposition with this filter is implemented for manipulating a high dynamic range image, which consists of three detail layers and one base layer. An effective function is used for compressing the detail layers. A noise reduction, based on subband decomposition followed by separately filtering the LL subband with bilateral filter and other subbands with soft thresholding and then the subband synthesis, is applied on this LDR image as the HDR image that was the input to the system consists of noise.

Keywords: LEP filter, Tone mapping, Noise reduction, HDR image, multiscale decomposition

1. INTRODUCTION

HDR image is one which has high ratio between the highest and lowest intensities in the image. The normal devices starting from the capturing devices (camera) to the display devices have reduced Dynamic Range (DR). So displaying of the HDR image on the comparatively Limited Dynamic Range (LDR) display devices require a transform, from the HDR to LDR while preserving the quality of the image, called the Tone Mapping (TM). Human Visual System (HVS) was taken into consideration for the sake of quality preserving. The feature of human eye which can only perceive a range of intensities and are blind to others is utilized and the intensity range that is visible to human eyes is enhanced. Humans are more sensitive to the high frequency intensities compared to the lower ones. Initially techniques called the Retinex Theory [5] was introduced where the image was decomposed to reflectance and illumination layers where the former consists of the high frequency components and the later consists of low frequency components. There were many solutions introduced to this problem statement but it was found that this definition of the layers was not distinct and clear that the result had problems such as edge smoothening or halo effects [6]. Earlier Gaussian filter followed by Bilateral filter was used which even though was effective had its own problem defining the parameters based on each image. Next the Edge preserving [6], [7] concept came into existence where the smoothening off of edges resulting in loss of details was considered. The local features using the window concept was used for this enhancement. The filter which was designed for this purpose was the Local Edge Preserving (LEP) filter. Here an image is divided into a base layer and different detail layers. The base layer not only contains the low intensities but also the higher intensity edges. Remaining intensity values are taken up by the detail layer. The output of the LEP filter is the base layer and taking the difference between the input to the filter and this base layer forms the detail layer. This process is done multiple times for the preservation of minute details and thus termed as Multiscale decomposition [7]. This process is limited to three times considering the time consumption and the analysis fact that further increase in number has not much effect on the same. The creation of HDR image from a number of HDR images is normally utilized in systems including camera and other display devices. Taking the image under different exposures and then combining them to form an HDR image is the routine. But as the number of images increase, so does the time taken for the creation. When this is limited the chance for noise is high as all the range is not preserved as required. Thus initially existing method utilized the concept that the higher 1% of pixels consists of the maximum noise and cuts off the portion and then stretch the image to 0,1 range. Alternatively a method to reduce noise using a noise reduction method is used and the remaining scaling process followed by color restoration is proposed as a change so the signal within the image increases.

2. PROPOSED METHOD

The tone mapping method accompanied by the noise reduction technique will increase the signal to noise ration compared to the one with tone mapping alone. The LEP filter proposed by Bo Gu et.al [1] is done by replacing the factor of cutting 1% of pixels, where noise is assumed to occur, by the noise reduction technique proposed by Lee et. al [2].

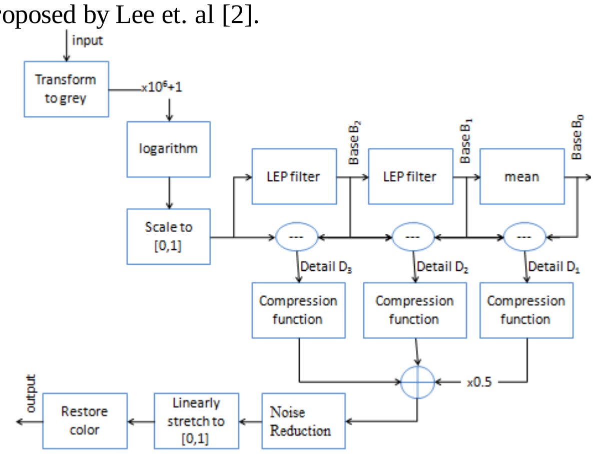

Figure 1 Block diagram of the proposed method

The various phases are given in the figure 1:

2.1 Local Edge-Preserving Filter

$$\sum_{i\in w}(I_i - B_i)^2 + \frac{\alpha'}{|\nabla I_i|^{\beta}}|\nabla B_i|^2 \quad (1)$$

The above energy function is the basis for the Local Edge-Preserving Filter [1] taken from [8], [9] which is solved using the Normalized Steepest Descent (NSD) method. Facilitating the solution, it is assumed that *B* is having a linear dependence corresponding to *I* in a local window. This is shown in the equation below:

$$B_i = a_w I_i + b_w \,, i \in w \quad (2)$$

where a_w and b_w are constant coefficients in the window w. Replacing B in (1) by (2) will give:

$$\sum_{i\in w}(I_i - a_w I_i - b_w)^2 + \alpha'|\nabla I_i|^{2-\beta}\, a_w^2 \quad (3)$$

This is adaptive to the gradient while theirs is a set parameter. This adaptive coefficient will preserve edges while others wont. Now the optimal problem becomes a parameter estimating problem. The minimum of (3) can be found by setting the partial derivative of each parameter to zero. This linear least squares solution is:

$$\begin{cases} a_w = \dfrac{\sigma_w^2}{\sigma_w^2 + \frac{1}{N}\cdot\alpha'\cdot\sum_{i\in w}|\nabla I_i|^{2-\beta}} \\ b_w = \bar{I}_w - a_w \bar{I}_w \end{cases} \quad (4)$$

Where σ^2_w is the variance of *I* in the window *w* and $\bar{I}_w$ is the mean of *I* in *w*. If α`=β`=1,then $\frac{1}{N}\sum_{i\in w}|\nabla I_i|^{2-\beta} = \frac{1}{N}\sum_{i\in w}|\nabla I_i|$ represents the average of the gradients in *w*. It can be easily deduced that a_w is always less than 1, and the contrasts of the output of equation (2) will always be compressed. In other words, *B* is a smoothed version of *I*. Each window contains *N* pixels, and each pixel is involved in *N* windows. For every window, there is a set of a_w, b_w, and then, the filtered output B_i of (2) has *N* different values. The values should be weighted averaged together to retain correct results and diminish distorted ones. However, the weights are hard to figure out, so here simply get the mean of all the N values of B_i. If a local window is identified by its central pixel, changing a_K, b_K for a_w, and *k* denotes the central pixels location. The LEP output is got as [10]:

$$B_i' = \frac{1}{N}\sum_{k\in w}(a_k I_i + b_k) = \bar{a}_i I_i + \bar{b}_i \,, i \in \Omega \quad (4)$$

where Ω represents the area of the image, and $\bar{a}_i$ is the average of the a_k in the neighbourhood window, and the same with $\bar{b}_i$. There are two parameters for LEP:α`,β They are relevant to the filters sensitivity to gradient. 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`orβ. Values for α`= 0:1or β= 1 is found to always produce satisfactory results, blurring details while preserving salient edges.

a. Multiscale Decomposition

The third assumption in the problem statement is approached by a Multiscale decomposition (the base layer should only contain zero gradients). A single LEP 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 LEP to the base layer will generate a multiscale decomposition. While iterating, the local window is increasing, which results in progressive coarsening. Let LEP_i denote the filter function, and l is the scale level, which also represents different local window radii at each filtering level. Then a sequence of progressively coarser versions of image I will be:

$$B_{l-1} = LEP_l(B_l)\,,\ for\ l = n, \ldots, 2, and\ B_n = I \quad (5)$$

The detail layers will get as:

$$D_l = B_l - B_{l-1}\ , for\ l = n\,, \ldots, 2 \quad (6)$$

In order to make the base layer contain only zero gradients, the mean of the base layer $B_1$is the last base layer B_0:B_0 = Mean (B_1). And then, D_1=B_1-B_0. Here, decomposing every image into three detail layers and one base layer (n=3) is done. This decomposition style is thought to address a basic idea that one decomposition for the fine scale, one for the medium scale, and one for the whole images scale. The process can be expressed by:

$$I = B_0 + D_1 + D_2 + D_3 \quad (7)$$

The process is that the salient edges are progressively decomposed into the detail layers.

b. Dynamic Range Compression

Since detail layers are oscillating around zero, a function is seeked to compress large deviations away from zero and enhance low ones. The compression function should be able to make the deviations at every point as equal as possible. The function should also be convex in order to avoid gradient reversal, and it should be symmetric about zero. Thus it is sigmoid, and one has been found:

$$y = 2\cdot \arctan(x\cdot 20)\,/\,\pi \quad (8)$$

The arc tangent function varies between π/2 and π/2, so it is divided by π/2 to compress the range to (0,1), in which the image pixel values are operated in this study. The multiplier 20 for input shrinks the shape of the arc tangent function, making it changing to at as quickly as possible. It is noted that almost all sigmoid functions work well here, but those, whose slopes are too large near zero, may cause artifact enhancement (e.g., some power functions). This function (8) takes in detail layers and puts out the compressed detail layers. The base layer is simply dropped as mentioned before. After the compression process, all the detail layers are summed up to give the result. A linear scaling to the normal range [0, 1] is also needed.

2.4 Noise Reduction

Since the LL wavelet consists of course grain noise bilateral filter is applied on it. The bilateral filter chosen here is Fast Bilateral Filter proposed by Durand et al [4].

$$I_p^{bf} = \frac{1}{W_p^{bf}} \sum_{q \in s} (\|p-q\|)\, G_{\sigma r}(|I_p - I_q|) I_q$$
$$W_p^{bf} = \Sigma_{q \in s} (\|p-q\|)\, G_{\sigma r}(|I_p - I_q|) \quad (9)$$

Soft-Thresholding [5] is applied on the remaining wavelets as they contains only fine grain noise.

$$\hat{b}_k^j(x) = \begin{cases} \operatorname{sign}\left(b_k^j(x)\right)\left(|b_k^j(x)| - \lambda_k\right), |b_k^j(x)| > \lambda_k \\ 0 \ otherwise \end{cases} \quad (10)$$

2.5 Color

All the process above is done on the luminance channel of an HDR radiance map, which is simply an average of the three color channels in this study. The color information is restored proportional to its original ratio. The equation used is the same as in [3], [11]:

$$C_{out} = \left(\frac{C_{in}}{L_{in}}\right)^s . L_{out} \quad (11)$$

where C = R, G, B represents the three color channels, and L_{in} , L_{out} denote the luminance before and after HDR compression, respectively. This function transforms the relationship of colors at level L_{in} to level L_{out}. The exponent s performs like a gamma correction for colors to be suitable for display. The exponent *s* values between 0.5 and 0.9 is found good for controlling color saturation of the result image. The larger the value of s is, the more saturated the result is. By default s = 0.6 is set in this study, since it gives good results for most images.

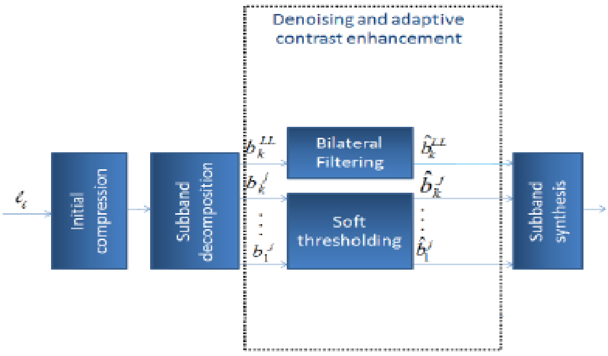

Figure 2 Noise reduction method –block diagram

3. Experimental Results

Experimental results based on values and assumption are provided below. Values for α`=0.1 and β=1 in (4) are set. The window size is inputted as an odd number. The value of s in color reproduction is given in as 0.6. Two objective are used as measures to assess the quality.

Table 1: Naturalness Values Comparison

Image	Existing LEP (Bo Gu et l.[1])	Enhanced LEP	WLS Filter
b1	**0.2536**	0.0724	0.1589
c1	**0.9325**	0.7273	0.5977
d1	0.5848	**0.6505**	0.3698
f1	**0.1542**	0.0530	0.0852
g1	0.0664	**0.0840**	0.0154
h1	**0.6519**	0.2592	0.0822
i1	**0.2505**	0.0719	0.1126
k1	**0.9601**	0.6515	0.7322

An assessment method is the recently proposed objective assessment especially designed for tone mapped images [12]. It combines a multi-scale structural fidelity measure and a measure of image naturalness. The structural fidelity measure is a full-reference assessment based on the structural similarity (SSIM) index, and the naturalness measure is a no-reference assessment based on statistics of good-quality natural images. This method provides a single quality score of an entire image. The combined single quality is represented by 'Quality'.

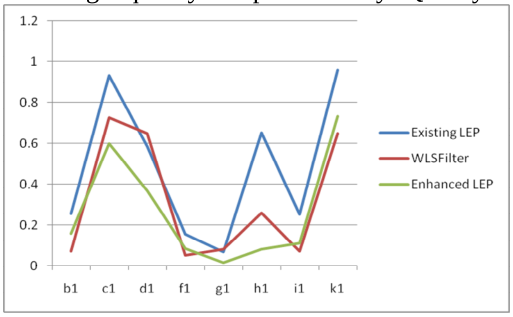

Figure 3 Plotting of the Naturalness values

One assessment measures image sharpness. An image is sharp means the details are clearly presented. The sharper an image is, the larger the measure is. It is defined as the normalized sum of total gradients:

$$S = \frac{1}{N} \sum |\nabla I| \quad (12)$$

where N is the number of pixels in image *I.*

Table 2: Sharpness Values Comparison

Image	Existing LEP (Bo Gu et al.[1])	Enhanced LEP	WLS Filter [6]
b1	**1.8751**	1.0635	1.1061
c1	**4.1224**	2.9694	2.5196
d1	4.4593	**4.6047**	3.9147
f1	**1.7354**	0.8628	1.1326
g1	**1.9783**	0.8530	1.0455
h1	**2.8831**	1.8719	1.6108
i1	**1.4755**	0.7528	0.9635
k1	**2.9338**	1.9251	1.8703

Figure 4 Plotting of the Sharpness values

Since image de-noising is applied its Peak signal to Noise Ratio (PSNR) is tested based on the HDR image created and this value will not be high as the data presented by the image is very high.

Table 3: Structural Fidelity Values Comparison

Image	Existing LEP (Bo Gu et al.[1])	Enhanced LEP	WLS Filter [6]
b1	**0.9620**	0.9354	0.7812
c1	0.0790	**0.9456**	0.8320
d1	**0.9669**	0.9561	0.9279
f1	**0.9213**	0.8626	0.6728
g1	**0.6458**	0.5811	0.3925
h1	**0.9781**	0.9351	0.8264
i1	**0.9666**	0.9241	0.7877
k1	**0.9799**	0.9466	0.8070

[Note: The X coordinate denotes the image names that is created using three consecutive exposure of the same scene and the Y coordinate denotes the corresponding plot values]

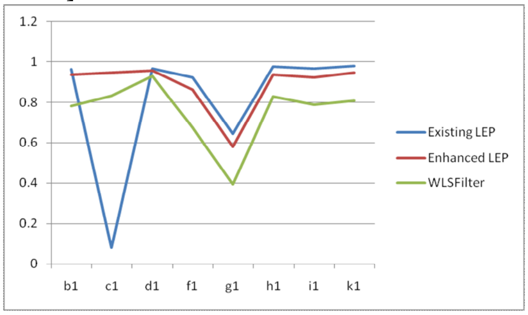

Figure 5 Plotting of the Structural Fidelity values

Table 4: PSNR Values Comparison

Image	Existing LEP (Bo Gu et al. [1])	Enhanced LEP	WLS Filter [6]
b1	15.4981	**19.5411**	18.2040
c1	15.4964	18.7791	**19.1601**
d1	16.0786	16.6118	**20.1236**
f1	14.3070	**20.5719**	19.2283
g1	13.7597	**15.5485**	14.3175
h1	15.6422	17.5934	**18.4456**
i1	15.6188	**18.4274**	17.4790
k1	12.6797	**18.7190**	18.3884

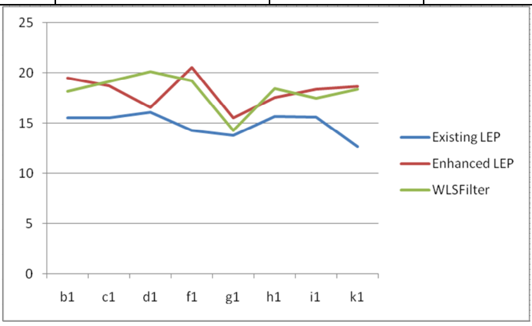

Figure 6 Plotting of the PSNR values

The value of existing system is less only for the PSNR comparison and it is seen that the other comparison is worth compared to other filters like WLS Filter to which the existing system has a priority. So even though the qualities like sharpness, structural fidelity and naturalness are a bit lower than the existing system it maintains the priority over other filters similar to the existing LEP Filter.

4. CONCLUSION

The quality of the image produced has been analyzed. There can be improvement in the value of the quality indices if they change the step of color restoration prior to the cutting of pixel step. The image can be enhanced if noise removal techniques are being used instead of the cutting 1% of the pixel. The present implementation has visible halo artifacts, which also can be dealt with in the future.

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