DENOISING AND ADAPTIVE CONTRAST ENHANCEMENT IN HDR IMAGE USING LOCAL TONE MAPPING

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Abstract—

Tone mapping is the process in which the color of a HDR image are mapped into a normal image. This paper propose a local TM algorithm which compresses the luminance of high dynamic range (HDR) image using a simple luminance compression function and decomposes the compressed luminance of HDR image into multi-scale sub bands using the discrete wavelet transform. For noise reduction, the decomposed images are filtered using a MADN filter and soft-thresholding. And then, the dynamic ranges of the filtered sub bands are enhanced by considering local contrast using the modified luminance compression function. Finally, the color of the tone-mapped image is reproduced using an adaptive saturation control parameter. Also detect the impulse noise based on the absolute deviation to the median in each cluster. Computer simulation with noisy HDR images shows the effectiveness of the proposed local TM algorithm in terms of visual quality as well as the local contras*t.*It can be used in various displays with noise reduction and contrast enhancement.

Keywords*— *tone mapping, contrast enhancement, subband decomposition, Normalized median absolute deviation (MADN) filter, high dynamic range

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I. INTRODUCTION

Tone mapping is technique used in image processing that map one set of color to another in order to approximate the appearance of high dynamic range image (HDR) in a medium that has a more limited dynamic range. TM algorithms have been developed for reproducing the tone mapped color image, in which color, the contrast, and detail components are enhanced using luminance compression by considering human visual system or the local statistical characteristic. Local TM algorithm constructs the tone-mapped color image with high contrast from the noisy HDR image.TM algorithms are classified into global [2] and local[11] algorithms in view of luminance compression. HDR is a range of methods to provide higher dynamic range from the imaging process. The two main sources of HDR images are computer rendering[1] and merging of multiple low-dynamic-range (LDR). Sometimes HDR image is captured using an HDR camera, which has high and low sensitivity sensors per pixel to increase DR. Also the dark region of HDR image has a low signal to noise ratio (SNR). The PSNR is most commonly used as a measure of quality of reconstruction of lossy compression. The signal in this case is the original data, and the noise is the error introduced by compression. PSNR is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. HDR image contains both coarse-grain (low-frequency)[8] and fine grain (high frequency) noise. Fine-grain noise is easy to reduce, whereas coarse-grain noise is relatively hard to smooth because it is difficult to distinguish between signal and noise [15]. Image denoising is one of the most fundamental, widely studied, and largely unsolved problems in digital image processing, and it has been studied for nearly half a century due to its important role as a preprocessing step in various image applications.

In this paper, we propose a noise reduction method and an adaptive contrast enhancement for local TM. Initially we compress the luminance of HDR image, the proposed local TM algorithm decomposes an initial compressed luminance into multi-scale sub bands using the stationary wavelet transform. The decomposed sub bands are filtered using a MADN filter (*LL* subband) and soft-thresholding (*LH*, *HL*, and *HH* subbands). And then, the local contrast is enhanced by an adaptive weight, which is derived from the luminance compression function with the color constraint [7]. Finally, the color of the tone mapped image is reproduced using an adaptive saturation control parameter[8]. Filtering is a method that removes noise and unwanted things from the image. The tone-mapped color image of the proposed local TM algorithm is compared with those of the conventional TM algorithms with post processing. Experimental results with the HDR images show that the proposed local TM algorithm efficiently reduces coarse- grain noise, enhances the local contrast of HDR images, and renders color naturally.

The rest of the paper is organized as follows: In Section II, we review the related work of our method. SectionIII, present our proposed local tone mapping which consists of image decomposition, denoising using a MADN filter and softthresholding, luminance compression by considering local contrast, and color reproduction. Experimental results with HDR images are presented and discussed in Section IV, showing the effectiveness of the proposed local tone mapping. Finally, SectionV conclude the paper.

II. Related Work

TM algorithm is used to compress the contrast, while preserving color ratio and details of the radiance map the HDR. The TM algorithms are classified into global and local [2]-[3] in views of luminance compression. Global TM algorithms are fast and simple also they are non-linear functions based on the luminance and using the same mapping curve for each pixel.

Developing a fast and robust edge preserving filter i.e, bilateral filter [2][13] that blur the small variations of signal but preserves large discontinuities. This filtering method which reduce the noise present in the image. Many acceleration techniques [2] can be adopted in the fast bilateral filtering. Yuanzhen Li et.al [4] design a multi-scale image processing techniques which have a reputation of causing halo artifacts when used for range compression. There are several method to derived a threshold value [14]. For denoising, an adaptive data driven threshold for image denoising such as wavelet soft thresholding [16] are used. . Ji et al[7] propose a color correction function(CCF) and image decomposition in high dynamic range imaging. CCF is derived from the luminance compression function (LCF) with the color constraint, under which the color ratios between the three color channels of the radiance map.

Reinhard *et al*.'s algorithm is a relatively simple and fast TM algorithm [2]. Li *et al*.'s algorithm uses a symmetrical analysis-synthesis filer bank, and applies local gain control to the subband [5]. iCAM algorithm is a new image appearance model, which incorporates the spatial processing models in the human visual system. Shan *et al*.'s algorithm performs local linear adjustments on small overlapping windows over the entire HDR image [11]. To generate the

HDR image, we apply Min *et al*.'s algorithm [13] to a set of three LDR images with different exposures and high ISO setting. HDR image is assumed to be generated by combining three LDR images with –1, 0, and 1 exposure value (EV) using auto exposure bracketing in a digital camera. However, the number of LDR images used in HDR image generation is limited in consumer products due to the processing time.

A new color appearance model (CAM) has been extended to a large response range which convert into the dynamic range of real world luminance. This model[5] will predict image attribute for complex scenes in a various luminance levels. For achieving better adaptive contrast certain parameters like hue, brightness, and saturations are preserved. High dynamic range image is mainly captured by means of HDR camera, which has high and low sensitivity sensors per pixel to increase dynamic range.HDR image is generated by combining LDR images, which are captured with varying exposure setting values[8]. All images contain different kinds of noise such as low-frequency and high frequency; some times it is difficult to reduce it. Low frequency noise is very hard to eliminate. Different types of wavelet thresholding techniques like Bayers Shrink, Sure Shrink are used for setting threshold value. The threshold can distinguish between the significant coefficients (signal) and the insignificant coefficients (noise).Our proposed tone mapping algorithm will effectively reduce the course-grain noise, impulse noise and speckle noise present in the image.

III. PROPOSED TONE MAPPING

The main goal of the proposed tone mapping algorithm is to construct a tone mapped image from the input image which are mainly HDR image

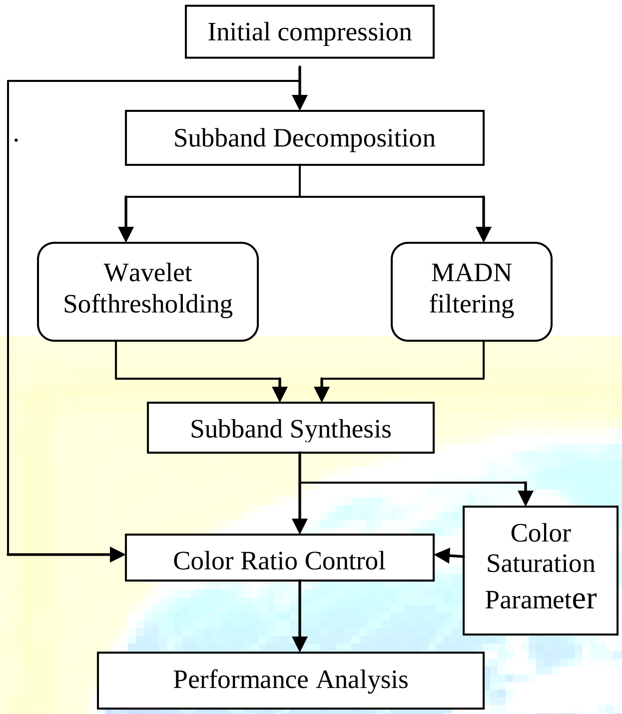

Fig.1 Block diagram for tone mapping

Fig.1 Shows bock diagram for proposed tone mapping algorithm. Each block can be described as follows:

A. Initial Compression and Subband Decomposition

Initially the luminance of the high dynamic range image is compressed using the luminance compression function. This function is a form of logarithmic function which reduce irrelevance and redundancy of the image data in order to be able to store the data in an efficient form. Then we decompose the compressed luminance by using stationary wavelet transform. The SWT is an inherently redundant scheme as the output of each level, stationary wavelet transform contains the same number of samples as the input so for a decomposition of N levels there is a redundancy of N in the wavelet coefficients. This wavelet mainly consist of low-pass filter and high-pass filter, which are very easy to implemented. They split sub band into $x=(x,y):b^{LL}(x),b^{LH}(x),b^{HL}(x)$, and $b^{HH}(x)$. The coarse-grain noise become fine-grain noise because of the number of multi-scale subbands increased.

B. Noise Rremoval using MADN Filter and WaveletSoftthresholding

In this paper, for denoising the image we are using MADN filtering and wavelet softthresholding. The low-frequency (LL subbands) are filtered by using MADN filter. The main objective is to recover the original image or the best estimation from while preserving image details.

Impulse noise is characterized by replacing a portion of an image pixel with noise values, leaving the remainder unchanged. This type of noise is introduced by transmission errors; to recover we are using median filters. For any datasets $x_1, x_2, \ldots, x_n$ the MAD is defined as the median of absolute deviation from the data's median:

$$MAD(x) = Med\{|x-med(x)|\} \quad (1)$$

$$Med(x) = Median\{x1,x2,..,xn\} \quad (2)$$

where the operation "Median" represents the median value of all the observations and x is the vector representation of data.

In soft thresholding, the wavelet coefficients with magnitudes smaller than the threshold are set to zero, but the retained coefficients are also shrunk towards zero by the amount of the threshold value in order to decrease the effect of noise assumed to corrupt all the wavelet coefficients. To apply soft thresholding on the wavelet coefficient $y(i,j)$

$$S\hat{}(i,j) = \begin{cases} y-T & if\ y(i,j) \geq T \\ y+T & if\ y(i,j) \leq -T \\ 0 & otherwise \end{cases} \quad (3)$$

where T= $\sigma\sqrt{2\log(n)}$ $y(i,j)$ is the standard deviation, n is the number of wavelet coefficient, $s\hat{}(i,j)$ are the denoised wavelet coefficient, T is the universal threshold, and the variance is estimated by using MAD method.

The soft thresholding function also used to smooth high frequency subbands, it can be denoted by

$$b_k^j(x) = \begin{cases} \sin\left(b_k^j(x)\right)\left(|b_k^j(x)| - \lambda_k\right), & |b_k^j(x) > |\lambda \\ 0 & otherwise \end{cases}$$

(4)

where $b_k^j(x)$ denotes high frequency sub band at each level k. A wavelet coefficient is compared to a threshold value and is set to zero if its magnitude is less than the threshold, otherwise, the wavelet coefficient is kept.

Fig.2(a) shows the original image without denoising 2(b) and 2(c) illustrates tone mapped images with denoising using different decomposition levels

C. Adaptive Local Contrast

In this local tone mapping method, we are applying adaptive contrast enhancement. Contrast enhancement is to adjust an image to emphasize features of interest. Contrast enhancement increases the total contrast of an image by making light colors lighter and dark colors darker at the same time. Contrast stretching based on statistical data taken from the neighbourhood of the pixel being processed.

The idea is to enhance contrast locally analysing local grey

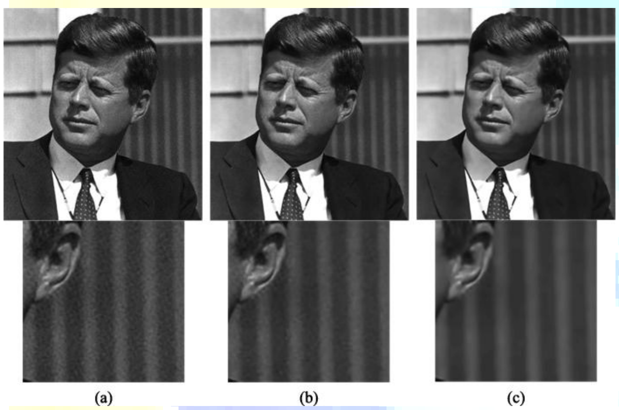

Fig.2.Performance Comparison denoising tone mapping with different number of decomposition levels K(a)original image (b)(K=1),(c)(K=2) differences taking into account mean grey level. The adaptive compressed luminance l_o is generated by,

$$l_0(x) = w(x) \cdot \hat{b}_k^{LL}(x) + \sum_{k=1}^{K} \hat{b}_k^{j}(x) \quad (5)$$

where $\hat{b}_k^{j}(x)$ denotes high frequency subband without noise w(x) denote adaptive weight at *x*. Fig3 specifying locally adaptive enhancement of image,3(a) denotes original image captured by camera 3(b) (c) be enhanced image after applying the luminance function.

D. Color Enhancement

To assign the color of the tone-mapped image, we use an adaptive color saturation control parameter. Contrast is defined as the separation between darkest and brightest areas of the image.

In the over-exposed region such as reflected area, bright sky, streetlights, and outside of the window in a sunny day, the color saturation control parameter *s* is set to a small value to reproduce natural color. In the under-exposed region such as shaded area and inside of the building, the color and details are rendered well in the tone-mapped image with a large color saturation control parameter *s*. The automatic color saturation control parameter *s* at **x** is determined by

$$s(x) = min\left\{s_{max}, \frac{a}{l_{o(x)}}\right\} \quad (5)$$

where *a* is a scale constant, $0 \le a \le 1$. *smax* can be tuned to produce the tone-mapped color images with different saturation. The larger maximum value *s*max makes the tonemapped image visually more colorful. The default value of *s*max =1.0 produces visually satisfactory tone-mapped images.

Fig.4 shows the performance comparison of color enhancement with algorithms.Fig.4(a) is the original image captured by camera. Fig .4(b) shows the tone mapped image using Reinhard et al's algorithm and 4(c) specifies Shan et al's algorithm. Fig.4(d) illustrates that our proposed algorithm.

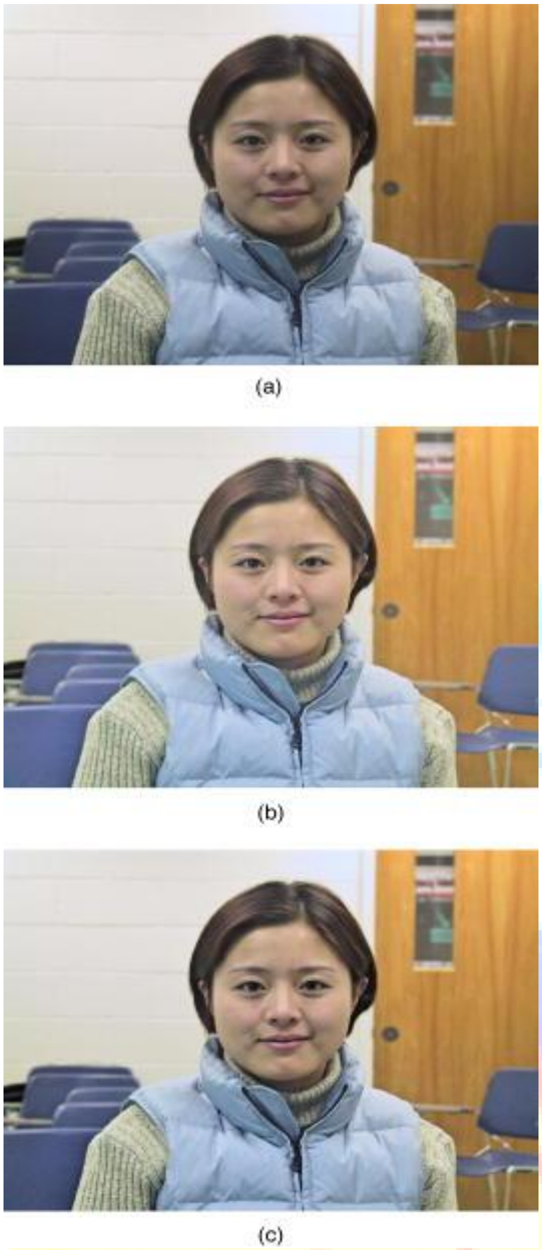

Fig.3 Performance comparison of adaptive luminance enhancement with different values(a) Original image (b)-(c) resulting images which satisfy all the adaptive saturation control parameters. Also it reduces the noise which are presented in the image.

IV. EXPERIMENTAL RESULTS

We use three LDR image sets to show the effectiveness of the proposed TM algorithm. HDR image is generated by combining three LDR images of the same scene but with under-, mid-, and over-exposures (–1, 0, and 1 EV).Fig.5 compare the local tone mapped images of scenery.

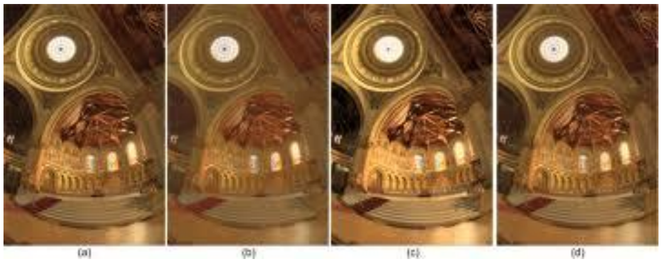

Fig.4 Performance comparison of color enhancement (a) original image,(b) Reinhard et al.'s algorithm,(c)Shan et al's algorithm,(d) proposed algorithm

Fig.5(a) shows the noisy HDR image which are captured by means of different exposure setting value and this image is corrupted with coarse-grain noise. Fig.5(b),5(c),5(d) and 5(e) shows the tone mapped images by Reinhard et al.'s [1],Li et al,'s[4], iCAM [5], and Shan et al.'s[10] algorithms.Fig.5(f) shows tone mapped image by the proposed local tone mapping algorithms, where coarse-grain noise is smooth and dark regions are greatly reduced.

Fig.5.Tone mapped images (a) HDR image,(b) Reinhard et al's algorithm,(c) Li et al.'s algorithm,(d) iCAM algorithm, (e)(Shan et al.'s algorithm,(f) proposed algorithm

Fig. 6 shows the performance comparison of 1-D intensity profile along a highlighted white line segment, which is indicated in noisy HDR image. The enlarged region is flat and dark. The 1-D profile of the noisy HDR image has low luminance value and fluctuation (noise). After TM using the conventional algorithms, the fluctuations (noise) remain, because TM algorithm enhances edge as well as noise. The 1-D profile of the proposed algorithm is relatively flat, because the noise is reduced using the MADN filter and soft-thresholding before contrast enhancement. Then we are using some saturation parameters to get the natural color of an image.

TABLE I

COMPARISON OF COMPUTATION TIME OF TM ALGORITHMS

TM algorithm	Reinhard et al.'s[1]	Li et al.'s[4]	iCAM[5]	Shan et.al's[10]	proposed
time	1	16.25	56.15	45.34	21.17

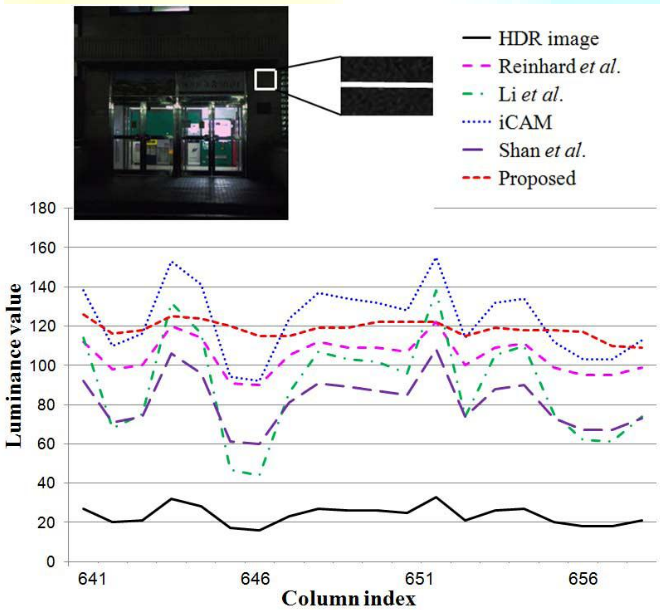

Fig.6 Performance comparison of 1-D intensity profiles along a line segment indicated in HDR image

Table I shows the performance comparison of the four conventional methods. The relative computation times of Reinhard *et al*. [2], Li *et al*.'s [5], iCAM [6], and Shan *et al*.'s [11] algorithms are 1, 16.25, 56.15, and 45.34, respectively. The relative computation time for proposed method is 21.17.

As Li *et al*.'s algorithm with the subband decomposition and iCAM based on the color appearance model are non-linear, and Shan *et al*.'s algorithm performs local linear adjustments on small overlapping windows and solves linear system over the entire input image, their relative computation times are long. For comparison of the relative computation time, we measure relative computation times with respect to Reinhard *et al*.'s method (=1.00)The conventional algorithms and the proposed algorithm have been implemented using Matlab code. We simulate on a 2.8 GHz Pentium 4 PC with 2048 MB.

The local TM algorithms apply different mapping curves to different regions or compositions of an image .Most local TM algorithms decompose an image into different scales or compositions. Lim *et al*.'s algorithm generates the multiple images with various exposures by applying the intensity mapping function and enhances the contrast using multiple images. Finally, we should comment on the contribution of the wavelet thresholding to the multiresolution framework (as mentioned earlier, in our experiments, we used the BayesShrink method for the wavelet thresholding part). We have done experiments with and without the wavelet soft thresholding. For real image experiments, the difference is barely visible.

In summary, experiments with several test LDR image sets show that the proposed TM algorithm reproduces better color of the tone-mapped image than conventional TM algorithms in highlight regions. It is because of the fact that, the gamma value used in color correction of the proposed TM algorithm is selected adaptively by considering the statistical characteristics of local regions.

V. Conclusions

This paper focus on a noise reduction method and an adaptive contrast enhancement for local TM. The proposed local TM algorithm consists of initial luminance compression, image decomposition, noise reduction, local contrast enhancement, image synthesis, and color enhancement. For image decomposition and synthesis, we use the stationary wavelet transform. The decomposed multi-resolution subbands are filtered using a MADN filter (*LL* subband) and wavelet soft-thresholding (*LH*, *HL*, and *HH* subbands) for reducing coarse-grain noise. Then, the local contrast is enhanced by an adaptive weight, which is derived from the luminance compression function with the color constraint. The color of the tone-mapped image is reproduced using an adaptive saturation control parameter. The tone-mapped image of the proposed local TM algorithm gives better image quality than those of the conventional TM algorithms. Experimental results with five HDR images show that the proposed local TM algorithm efficiently reduces coarse-grain noise, impulse noise and renders color naturally.

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