Indian Journal of Science and Technology, *Vol 8(36), DOI: 10.17485/ijst/2015/v8i36/63148, December 2015*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Analysis and Epigrammatic Study of Various Tone Mapping Operators for High Dynamic Range Images

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Abstract

Background: In Recent years Display of HDR images on yardstick LDR Displays with Tone mapping Operators (TMO) has many issues like halo artefacts, edge preservations and visual appearance. Always there exists a issue about usage of operator with regard to the input sequence without all these factors. **Objectives:** In this paper a thorough analysis is carried out with 31 TMO operators. Existing study papers are up to maximum of 8 TMOs, but this paper evaluates all the 31 operators and the objective quality measure is calculated. Researchers are carried out to identify a better operator for its own applications, which motivated to do this paper, the resultant analysis provokes to the development of a new method with lesser computational time. This work can be further extended to optimization of the algorithm used in fusion of base and detail layers of sequence of input. From the analysis the naturalness, structural fidelity and Quality of the image can be improved.

Keywords: Enhancement of LDR Image, High Dynamic Range Images, Local and Global Operator, Tone Mapping Operators

1. Introduction

In recent scenario the colour images of red, green and blue channels are represented in byte per pixels, i.e. RGB shades. Even after stating that there are only 256 values for red, green, blue, the components in combinations can produce of each pixel, 1.6million colours. Hence, this technique can be used in imaging and photography to reproduce a greater dynamic range of luminosity. 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 are 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 low dynamic range images are converted to high resolution by the HDR imaging technique, with radiance mapping, hence resulting in a High Dynamic Range Images. As compared to the conventional imagery, the fidelity of the HDR images is much higher. HDR image is the result of the fusion of multiple exposures of the single image. Generally, the photographs taken in Non-HDR cameras got exposed to very limited range, hence resulting in the loss of details in bright or dark areas[1–4].

Alternately, the multiple photographs are captured with different level of exposure and different shutter speeds and combined into a single image. There are two methods in construction of HDR imaging, one is to construct the different intermediate maps and render the HDR Image and another method is to merge multiple Low-Dynamic-Range (LDR)[5] or Standard-Dynamic-Range (SDR)[6] photographs. HDR images are acquired from special image sensors, like oversampled binary image sensor cameras. Tone mapping operator helps to preserve the original colours and remove the artistic colour. Tone mapping methods reduces overall contrast to facilitate display of HDR images on devices with lower dynamic range. The display depends on the display device, whether it is a LDR monitor or the HDR monitor. Some of the recent HDR monitors enable the HDR image by compressing

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the dynamic range. As the tone mapping operators are improved the availability of such HDR monitors are growing rapidly in the market. Natural scenes have a wide range of illumination conditions, ranging from night scenes to outdoor scenes. But when we see these scenes, they differ because of illumination from one scene to another by perception. Illumination also plays a vital role in the range of the image.

2. State -of -Art

Tone-Mapping Operators (TMO) are designed to generate perceptually similar low dynamic range images from high-dynamic range ones. Whereas from multiple exposure LDR images we get a high dynamic range again they have to be displayed in LDR monitor. So TMO operators are used for the conversions. There are many tone mapping operators in the literature, but the operators depends on the applications and the camera response. The performance of the TMO depends on the lighting and viewing conditions, local and global assumptions made on the aesthetic and realistic colors and preferences.

Capturing devices can display the image with flare correction and approximate radiances. One of the important tasks of the camera is to simulate the processing of the HVS and to make its representation more perceptual. The Figure 1 shows HSV process of the scene with different adaption. the idea behind the TMO algorithm is to match the real scene to that of imaging device. The tone mapping algorithms are classified as local and global operators. Kuang et al., tested different tone mapping algorithms using 10 HDR images. The experiment was carried out by implementing two paired comparison psychophysical experiments which generally helps to assess the color and grayscale tone mapping performance respectively. Ledda et al.,[20] presented the test results by evaluating six tone mapping algorithms by comparing to the references scene displayed on HDR display. These HDR displays allow to execute with statistical method and the overall quality

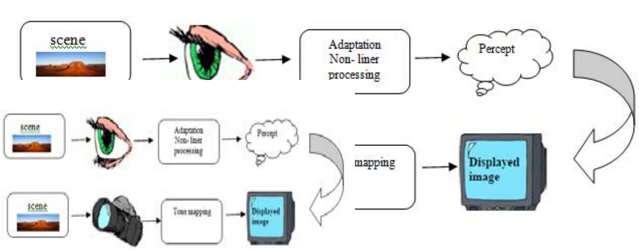


Figure 1. The processing of HSV.

measured. Yoshida et al.,[32] compared different tone mapping methods on two architectural interior scenes. The 14 observers were asked to rate basic image attributes as well as naturalness of the images by ratings. The results of this perceptual study exhibited differences between local and global tone mapping operators, comparatively local shows better outcomes. Recently, the researchers have focused on developing new models for extending the dynamic range of LDR content in order for it to be used in the applications such as Image-Based Lighting (IBL) or for viewing on HDR displays. Inverse Tone mapping Operator (iTMO) can be classified based on image processing technique. For example, global operators or local operators Reinhard et al.,[3] provided good overview and implementation in terms of perception.

Schlick and Tumblin et al.,[7] proposed a S shaped function which preserves the details in the shadows, but the drawback is contrast is reduced. There are few papers which refers a noble histogram adjustment operator which disregards the empty portion of the histogram resulting efficient contrast reduction. However the limitation due to the global nature of the technique becomes obvious when the input exhibits uniform histogram as referred by Cohen and Jonathan[5]. Most of the Local tone mapping techniques uses a decomposition of images into different layers or scales which uses vibration techniques with which the contrast is reduced. The major pit fall of local method is the presence of haloing artifacts. Chiu et al.,[8] vary again according to a low pass version of the image which results in pronounced halos. Pattenik et al.,[9] proposed operator to process a stream of input images of a scene and produce the output stream that simulates the changes in visual appearances caused by variation in the scene luminance. Since the concept of HDR color space is new, no experience within image application has been gained so far. Therefore, a new gamut mapping is proposed by improving the color image difference. Drago et al.,[10] proposed a tone mapping operator with adaptive logarithmic mapping strategy by changing the logarithmic function based on luminance level. Michaeal[12] developed a global tone mapping operator which is better in visualization compared with other tone mapping operators. Tumblin and Turk et al.,[14] proposed a local tone mapping operator with layer-based method which is used for preserving the edges and filtering anisotropic diffusion. Durand and Dorsey et al.,[11] developed a simpler layer-based method for using base layer and detail layer. Lee et al.,[16] proposed a local tone mapping operator with bilateral filtering method for the adjustment of base layer using global mapping function and enhancement of detail layer using gain map obtained in base layer. Krawczyk proposed a local merging framework with luminance value to segment the HDR image. Lischinski et al., introduced a novel interactive local adjustment method to have better tonal values with greater visual parameter.

Adaptive logarithmic mapping provides consistent result by avoiding artifacts and addressing halos with contrast adjustment. The principle character of logarithmic tone mapping function is an adaptive adjustment of logarithmic based depending on each pixel's radiance. The interpolation luminance value is found in the scene from $\log_2(L_w)$ to $\log_{10}(L_w)$. This provides good contrast and detail preservation in dark medium areas while permitting maximum compression of high luminance value with the knowledge about various tone mapping operators. Here, we proposed Hybrid Tone mapping Operator (HybridTMO) as a part of work and the subjective quality assessment is carried out and the results has been discussed. There are 30 tone mapping operator and one false color producing operator. All these tone mapping operator have been tested and the results have been stated.

3. Classification of Tone Mapping Operator

The visibility, brightness contrast and the color of an image is preserved by the tone mapping operator. The image is generally represented either in gray or in basic RGB color. The tone mapping operators applies the transformation or some enhancement technique on the colour channels so that the contrast and the saturation can be improved. The color channels are independently processed hat is the operation is performed on each color channels. While individually processing the channels its is meant that the luminance or the chrominance the channel is tried to modified. In general the world luminance is different from the display luminance. The high dynamic Range image can be obtained by tone mapping, this world luminance into the display luminance. These operators can be broadly classified as local tone mapping operator and global tone mapping operators. The Figure 2 represents the general classification based on the operations.

3.1 Global Tone Mapping Operators

Tone mapping approach and exposure fusion are two methods to combine multiple exposed images into a single

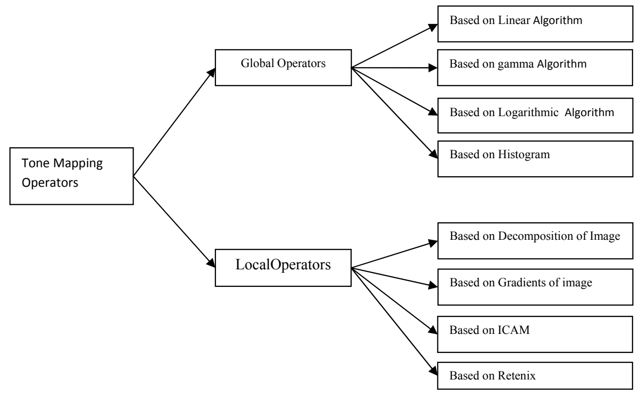


Figure 2. Classification of tone mapping operators.

image, of which exposure fusion is the recent one. They produce better results, though both have their own advantages and differences in their approach. The first concept of Tone mapping procedure was introduce by Tumblin and Rushmeier in 1993[7]. First tone mapping operator was introduced to reproduce the High Dynamic Range of Image in the display device nearing to the camera luminance that is better than the world luminance. 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 Devlin[8]. The global operators are the linear mapping, presented by the methods of Pattanaik[8], Ward[9] and Drago[10]. The local operators are the fast bilateral filtering, presented by Durand and Dorsey[11], Ashikhmin[12] and Reinhard[13] methods. The Range of RGB color is 0-255. One of the simplest tone reproduction method is linear tone reproduction, where the radiance is scaled to 0-255, and is called logarithmic linear mapping. An histogram based tone reproduction also gives an excellent results nearer to the natural luminance[14,15]. While converting the world luminance to device luminance the image compression has to be done. The compression is based on the logarithmic compression of the contrast from log2 to log10 with increased compressive power[16].

3.2 Local Operators

The local tone mapping differs from global by using the operator. The averaging or the smoothening method is followed in the global and the sharpening is done pixel by pixel in local operator. The most recent version of tone mapping operators is available without setting the parameters[17]. The automated process is carried out by low contrast region is identified in different scales. After the identification of low contrast region the dodging method is applied locally to enhance the contrast, while applying the local tone mapping the luminance is corrected in overall image pixel by pixel which enhances the color. Ashikmim works with different approaches human visual system and the signalling the brightness. In this method the adoption luminance is calculated from the neighbouring pixel which fit into the color contrast range similar to Reinhard[13] then with the help of threshold function and the capacity function the final image is restored without using the compression. Dorsey[11] proposed a method in which we use a fast bilateral filter to separate the image to spatial frequency layer like base layer and the detail layer. The base layer has the high contrast edges and removes the low contrast edges. The detail layer creates the difference in the low contrast frequency to the original image with logarithmic scale. In Figure 3, the sample multiple exposure image is shown, 10 multiple exposure image is taken as input. Some of the example tone mapped operator results are also given. The selection of local and global tone mapping operation depends on the input and the application of the image. So this study gives the output of various operators which helps you to make a clear decision in selecting the operator.

4. Steps Involved in Tone Mapping

Hollow artefacts and greying out are some of the issues in HDR image rendering. There are many methods available to increase the contrast of the image but here the local contrast is enhanced without introducing the false color. Some times while increasing the local contrast there is a possibility of reduction in visibility, hence most of the methods apply gamma correction. 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 as given in the Figure 4. 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.

5. Tone Mapping Operators for Videos

There are many tone mapping operators are available for videos which are listed in Table 1. Some of the operators listed below and the experiment is carried out to check quality of various tone mapping operators for

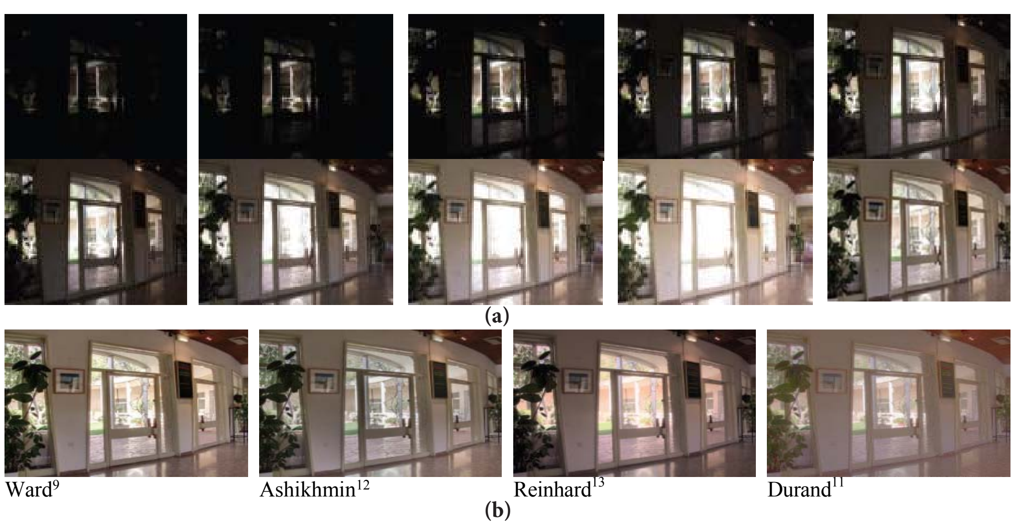


Figure 3. **(a)** Multiple exposure input images. **(b)** Some of examples of Tone Mapping Operators (both Global and Local).

STEP1: Input the RGB values of Radiance .

STEP2: (I_m) =R+G+B/3

STEP3: Calculate the chrominance channels: (R/ I_m), $G/ I_m)$, $B/ I_m))$

STEP4: Calculate the log intensity: $L_{inty} = \log2(I_m))$

STEP5: Apply a suitable filter $B = bf(L_{nty}))$

STEP6: Compute the detail layer: $D = L_{nty} - B$

STEP7: Apply an offset and a scale to the base: B' = (B - o) * s

7.1 The offset is choosen such a way that the maximum intensity of o is 1. So the values are in the log domain, o = max(B).

7.2 The scale is set so that the output base has dR stops of dynamic range, i.e., s = dR / (max(B) - min(B)). Where the value between 4 to 5 is fine.

STEP8: Again Reconstruct the log intensity: O = 2^(B' + D)

STEP9: Replace the original colors : R',G',B' = O * $(R/I_{nty}$, G/I_{nty}, $B/I_{nty})$

STEP10: Apply gamma compression. Without gamma compression the result will look too dark. Values around 0.5 should look fine (e.g. result.0.5). Apply the simple global intensity scaling to the final output.

Figure 4. Steps involved in tone mapping.

Table 1. The Quantitative assessment results of all the tone mapping operators for one dataset

S. No.	OPERATORS	Q	S	N
1	Ashikhmin TMO	0.2149	0.0133	$8.0542e^{-12}$
2	Banterle TMO	0.2159	0.0135	$7.4103e^{-13}$
3	BruceExpoBlend TMO	0.1974	0.0101	$4.1891e^{-12}$
4	Chiu TMO	0.1963	0.0099	$2.3138e^{-13}$
5	Drago TMO	0.2159	0.0135	$7.4103e^{-13}$
6	DurandTMO	0.2144	0.0132	$2.8752e^{-13}$
7	ExponentialTMO	0.2041	0.0112	$1.7710e^{-12}$
8	FattalTMO	0.2102	0.0124	$3.8080e^{-13}$
9	FerwerdaTMO	0.2162	0.0136	$3.1808e^{-13}$
10	GammaTMO	0.2146	0.0132	$3.6238e^{-13}$
11	KimKautzConsistentTMO	0.2162	0.0136	$9.8546e^{-13}$
12	KrawczykTMO	0.1905	0.0090	$1.6868e^{-12}$
13	LischinskiTMO	0.2191	0.0142	$2.2964e^{-12}$
14	LogarithmicTMO	0.2151	0.0133	$1.8683e^{-13}$
15	MertensTMO	0.2081	0.0120	$3.1959e^{-12}$
16	NormalizeTMO	0.2157	0.0135	$2.4735e^{-13}$
17	PattanaikVisualAdaptationStaticTMO	0.2111	0.0125	$2.0901e^{-19}$
18	PeceKautzTMO	0.2146	0.0132	$3.6898e^{-13}$
19	RamanTMO	0.2111	0.0125	$7.3752e^{-13}$
20	ReinhardBilTMO	0.2159	0.0135	$7.8123e^{-13}$
21	ReinhardDevlinTMO	0.2122	0.0128	$5.2556e^{-14}$
22	ReinhardTMO	0.2155	0.0134	$4.5779e^{-13}$
23	SchlickTMO	0.2148	0.0133	$1.6145e^{-12}$
24	TumblinRushmeierTMO	0.2118	0.0127	$6.4609e^{-15}$
25	VanHaterenTMO	0.2115	0.0126	$5.6097e^{-17}$
26	WardGlobalTMO	0.2121	0.0127	$2.4316e^{-15}$
27	WardHistAdjTMO	0.2168	0.0137	$6.7550e^{-13}$
28	YeeTMO	0.2140	0.0131	$6.6654e^{-12}$
29	ZhangChamGradientTMO	0.1867	0.0084	$3.8373e^{-12}$

(*Continued*)

single image. As we perform tone mapping for static image there are number of operators available for vedio processing. These operators can also be classified as local and global operators. Some of the global operators are Visual adaptationTMO[18], Time adaptationTMO[19], MaladaptationTMO[21], Virtual exposures TMO[22], Cone model TMO[23], Display adaptive TMO[24]. These operators work with the basis of threshold visibility, Psychophysical measurements based filtering, retina based model is used for enhancement. Likewise few local tone mapping operators like Local adaptationTMO[20], Virtual exposuresTMO[22], Retina model TMO[25], Color appearance TMO[26], Color appearanceTMO[26], TemporalcoherenceTMO[27], Camera TMO[28] are used for local contrast enhancement.

6. Qualitative Analysis of Various Tone Mapping Operators

As we discussed in section 5 different tone mapping used for images for our quality assessment. Measuring the image Quality is a major research area of its own, and HDR images add further variables due to the large luminance variations between closely neighbouring regions of images. While the LDR metric can be verified through visual inspection and user tests. It is very difficult to masses the severity of HDR images distortion. The Quality metrics that are widely used are HDR –VDP is proposed by Mantiuket et al.,[24], this simulates the features of the human visual system to compute a likelihood of detection for each change between two images. Based on logarithmic response of human visual system Xu et al., used color space root-mean square error metric. PSNR metric works by converting the original HDR into multiple LDR images at different exposures, then computing the peak signal – to-ratios of individual images. Ward has measured the quality using a modification of CIE delta E metric, where the reference white level for each image is taken from the brightest pixel within a certain radius. These metrics were promising but the latest paper gives a quality metric in terms of naturalness, Quality and Structural fidelity. In this paper objective quality assessment algorithm for tone mapped images by combining a) multi scale signal fidelity measure on the basis of a modified structural similarity index and b) naturalness measure on the basis of intensity statistics of natural images.

7. Quality Assessment of Various Operators

The SSIM approach is a design philosophy/practical method for measuring structural fidelities between images. The original SSIM algorithm is applied locally and contains three comparison components – luminance, contrast and structure[29].

7.1 Statistical Naturalness (N)

A high quality LDR image must look natural. A study in naturalness provided useful information regarding the correlations between image naturalness and different image attributes such as brightness, contrast, color reproduction, visibility and reproduction of details. The results showed that among all attributes being tested brightness and contrast have more correlation with perceived naturalness so a statistical naturalness model based is referred based on these two attributes.

$$N = \frac{1}{K} P_m P_d \tag{1}$$

The Naturalness can be obtained with the above mentioned equation. Where K is a normalization factor given by $K = \max\{Pm\ Pd\}$. This constrains the statistical naturalness measure to be bounded between 0 and 1.

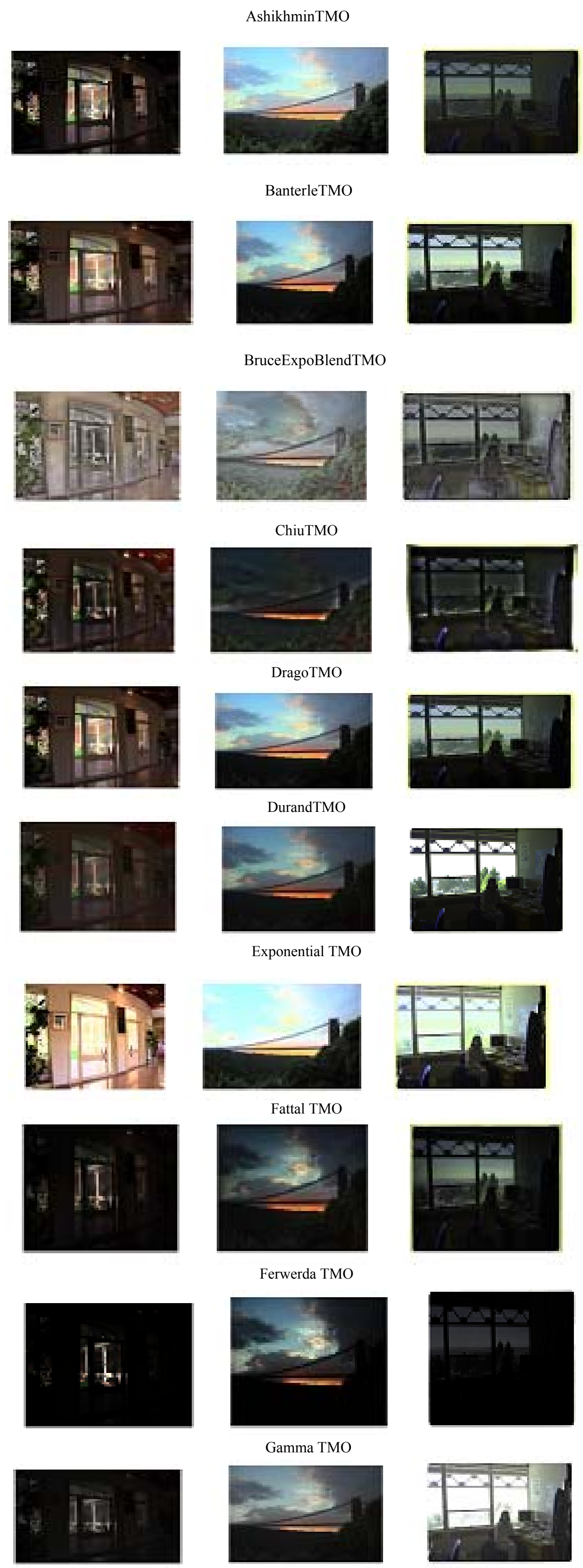
7.2 Quality Assessment Model (Q)

The structural fidelity S and the statistical naturalness N tells us the quality of tone mapped images. They may be used individually or jointly as a vector valued measure.

7.3 Quality Index (TMQI)

$$Q = aS^{a} + (1-a)N^{\beta} \tag{2}$$

where $0 \le a \le 1$ adjusts the relative importance of the two components, and α and β determine their sensitivities, respectively. Since both S and N are upper-bounded by 1, the overall quality measure is also upper-bounded by 1. These metrics are used in validating all these operators and the results are tabulated in Table 2.



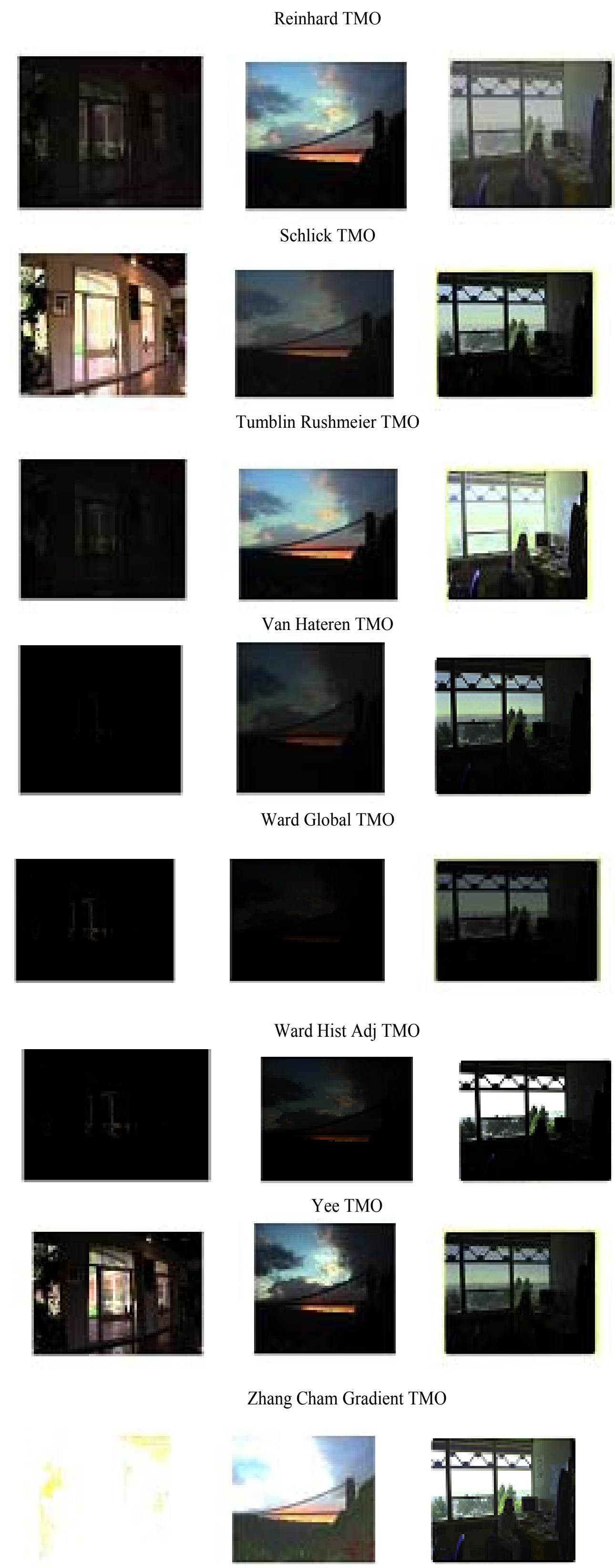


Figure 5. Output of various tone mapping operators for three datasets.

8. Conclusion

A brief study of the various operators is given above, which helps in identifying the operators according to the need of enhancement. Three data set is taken for experiment and the results are shown in the Figure 5. 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 Table 2. 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 in tone mapping operator resultant image is an HDR image and in fusion image is LDR image. The future work will be honey bee optimization of these operator.[31].

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