A Novel Technique for Tone Mapping of HDR Images

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Submitted By

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled, "*A Novel Technique for Tone Mapping of HDR Images*", in partial fulfillment of the requirements for the award of degree of Master of Technology in *Computer Science and Application* submitted in Computer Science and Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of *Mr. Shatrughan Modi* and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.

(Himanshu Kasliwal)

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

The images are quite useful for human understanding. It is an easy medium for visualizing the things. One picture is more worth than ten thousand words. High Dynamic Range imaging is used to capture the scene of the real world, so that the bright or dark areas will not be saturated in the output image. A *high dynamic range* (HDR) image uses a large bit depth up to 32-bit per pixel per color channel. Due to hardware limitation, it can neither be captured by conventional camera in a single photo, nor be displayed on a conventional monitor. The tone mapping method is used so that high dynamic range images can be displayed on the conventional display devices. Different methods of tone mapping have been proposed in the past.

In this thesis a new tone mapping technique is proposed. In this technique a High Dynamic Range (HDR) image is taken as input and it is decomposed into two layers i.e. base layer and a detail layer. The details of HDR image will be preserved because only the contrast of the base layer is reduced. To obtain the base layer a bilateral filter is used. On the base layer the logarithmic compression is applied and a bias power function is used so that the logarithmic base can be varied adaptively and the contrast remains preserved. In the final step gamma correction is applied to improve the contrast in the dark areas of the image. This tone mapping technique produces a high quality tone mapped images as specified in experimental results.

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Chapter 1

Introduction

1.1. Digital Image Processing

A 2-variable function $f(x, y)$ can be defined as an image, in which x and y are the coordinates of the plane, and f is the value, which can be defined as the intensity or gray level at any point (x, y) in the image. An image can be called as digital, if the values of x, y and f are finite and discrete. If the images, which are digital in nature, are processed by using a digital computer, it is referred to as *Digital image processing.* In a digital image, there are elements with a finite limit and each element has a location and its corresponding value. The elements are known as *pixels* [1]. Figure 1 shows how a digital image is acquired.

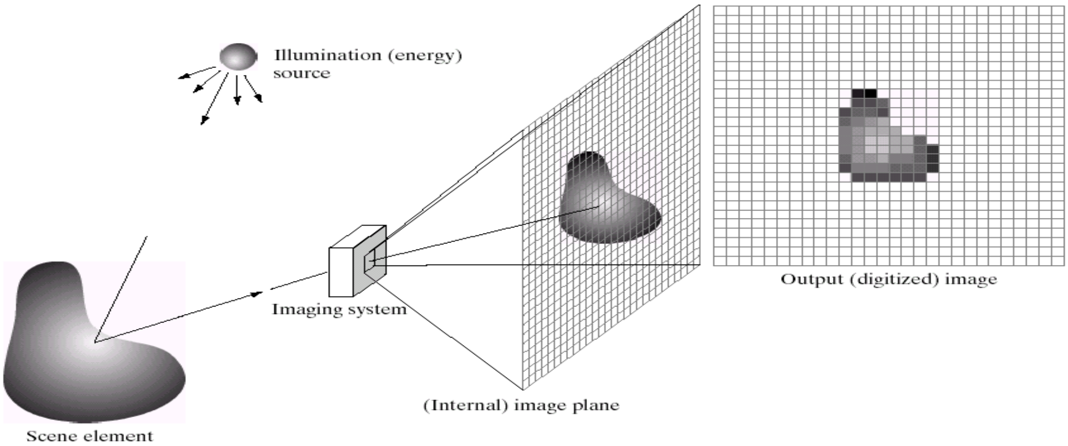


Figure 1.1: A digital image acquisition process [1]

For the acquisition of a digital image, different ways can be used but the overall goal is to obtain a digital image by using the sensed data. Most sensors produce the output in the form of continuous voltage waveform. In order to obtain a digital image from this sensed data, two processes are used i.e. *Sampling and Quantization.* When an image is captured using the camera, it is in continuous form and the plane coordinates x, y and the amplitude f are also continuous. To obtain a digital image, we have to apply a function on the x, y plane coordinates and also on amplitude f. The process of digitizing the plane coordinate x, y is referred as Sampling. The process of digitizing the values of amplitude f is referred as Quantization [1].

1.1.1. Computerized processes involving Digital Image Processing

The computerized processes where the digital image processing is involved can be categorized into three types:

1.1.1.1. Low Level Processes

In the low level processes, the main operations of image processing include reduction of noise, enhancement of contrast, image sharpening etc. In low level processes, the input and output both are images. In these processes basically the quality of the image is improved so that its visibility would be clear for the user. The low level process is basically used for the enhancement of the image for improving the human perception.

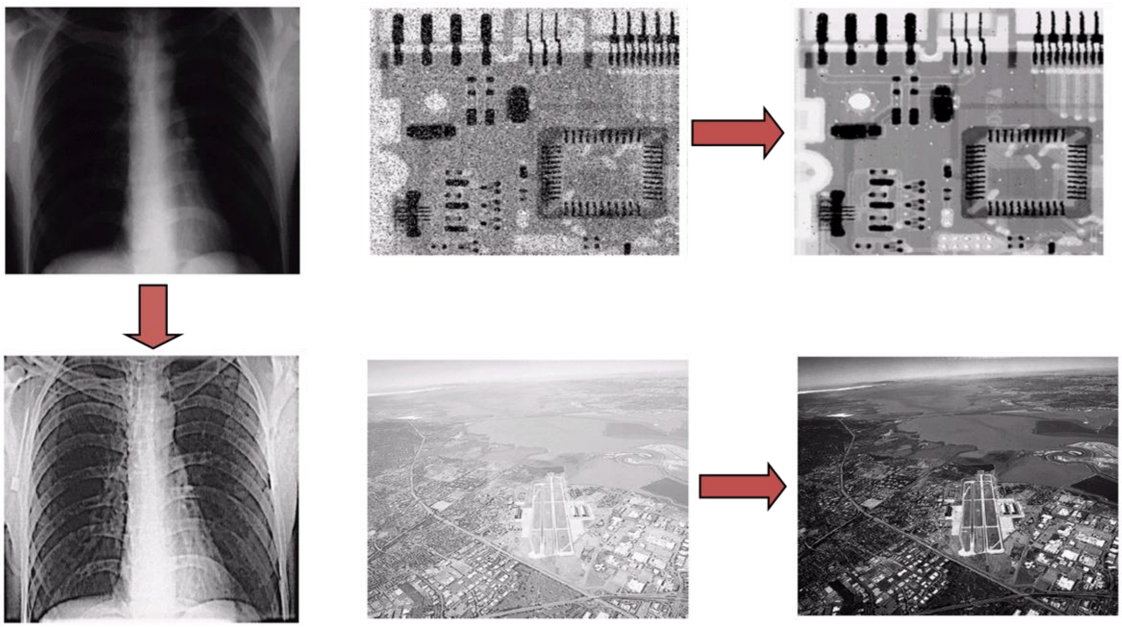


Fig. 1.2: Image enhancement using Low level processes [1]

1.1.1.2. Mid-level Processes

In the mid-level processes, the operations which have been performed on the images are like segmentation which can be defined as decompose the image in the form of objects or regions, also describe these objects or regions so that it can be reduced in a form which is suitable for the processing by the computer and individual objects can be recognized or classified. The characterization of mid-level processes can be done with the thing that the inputs are in the form of image, but the outputs are attributes which are extracted from those images. This attributes can be edges, contours or an individual object which is identified.

(a) Original Image **(b) Segmented image**

Figure 1.3: Example of Mid Level Process

1.1.1.3. High level Processes

In the high level processes, the main operations of image processing which have been involved are like making sense from the recognized objects, image analysis etc. In the high level processes basically the information is extracted from the images. In various fields like medical imaging where different kind of information can be extracted by using image analysis. The high level processes are also used in cognitive functions which are generally used with vision. The high level processes are also used in machine vision applications. When the products are assembled and inspected, also for automated detection and tracking of targets, recognition of fingerprint, prediction of weather, assessment of crop etc.

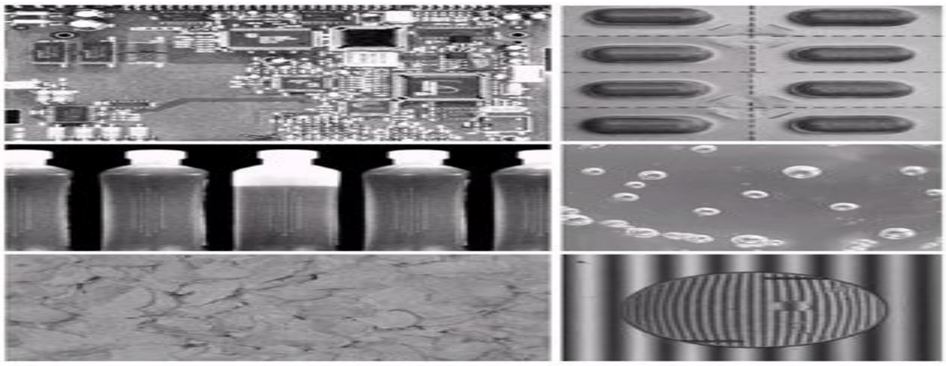


Figure 1.4: High Level Process in machine vision [1]

1.2. Color Space

To represent the color in the form of its intensity values, a model is defined which is known as color space. In general, a 1- to 4-dimensional space is defined by a color space in which a color channel or a color component is one of its dimensions. The gray-scale space can be represented by the color dimensional space, *i.e.* one dimension per pixel. The two models which are used in the proposed method are as follows [2]:

- RGB Color Model
- YCbCr Color Model

1.2.1. RGB Color Model

The three primary colors of the RGB Color Model are Red, Green, and Blue. Typically, in most of the CRT monitors and also in the color raster graphics systems, RGB color model is used. It is known as an additive color space because to reproduce a variety of colors, Red, Green and Blue colors are added in different ways. The Cartesian coordinate system that is used by the RGB color model is shown in Figure 1.5. The gray-scale has been represented by the diagonal-form in which (0,0,0) is represented as black and (1,1,1) is represented as white. Figure 1.6 has been used to represent the RGB color model [2].

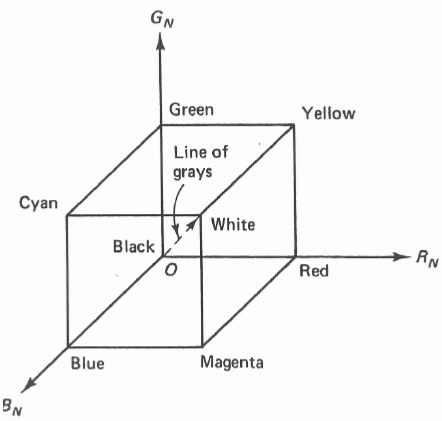


Figure 1.5: RGB Coordinates System [2]

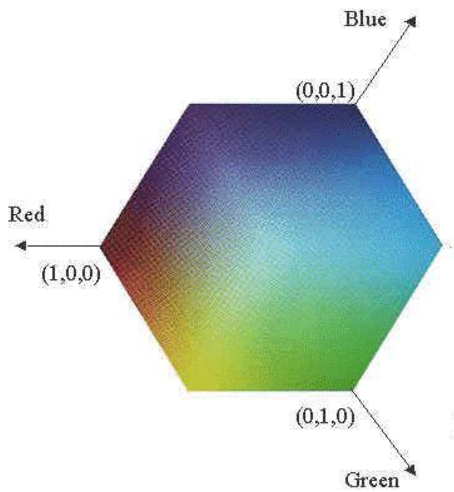


Figure 1.6: RGB Color Model [2]

1.2.2. YCbCr Color Model

YCbCr color space is generally used in the field of color image pipeline for video systems and also in the digital photography systems. The Y component is defined as the luminance component and Cb and Cr components are defined as chroma components of the blue-difference and also the red-difference respectively. The Y component is used for the luminance which means that the intensity of light is encoded nonlinearly on the basis of the RGB primaries after the gamma correction [3].

It is a color model which is not absolute; it is encoded by using the RGB information. The true color which will be displayed depends on the basis of RGB primaries, which are used for displaying the signal. It means that any value that is expressed in the form of YCbCr can be predictable if the chromaticities of the standard RGB primaries are used. The equation for converting the RGB color model to YCbCr color space and from YCbCr to RGB color space is defined by equations 1.1 and 1.2 [3].

RGB to YCbCr:-

$$\left\{ \begin{array}{c} Y = 0.213R + 0.715G + 0.072B \\ Cb = -0.117R - 0.394G + 0.511B + 128 \\ Cr = 0.511R - 0.464G - 0.047B + 128 \end{array} \right\} \tag{1.1}$$

YCbCr to RGB:-

$$\left\{ \begin{array}{c} R = Y + 1.540(Cr - 128) \\ G = Y - 0.459(Cr - 128) - 0.183(Cb - 128) \\ B = Y + 1.816(Cb - 128) \end{array} \right\} \tag{1.2}$$

1.3. High Dynamic Range Imaging

In the real world, light intensity span from very dim to very bright. The traditional imaging devices can capture a limited range of intensities. So, whenever a high light contrast scene is captured by using the conventional camera, either area which is dark or area which is bright tends to be saturated in the captured image because the normal camera uses 24 bits per pixel means 8 bits for every color channel means it has only 256 discrete intensity values for every color channel in the image. This is far less than the dynamic range of real world. This is the reason behind the saturation of areas which are dark or bright from the scene of real world. To overcome this problem the introduction of High Dynamic Range (HDR) imaging has been done. In HDR imaging the original real world scene is recovered by using multiple traditional Low Dynamic Range (LDR) images [4].

HDR images are created by taking multiple LDR images at different exposure intervals Δt. When the time of exposure is short, the bright area of the scene will be captured and when the time for exposure is larger the darker area will be captured in the image and after that, by fusing this multiple LDR images, original scene will be obtained [4].

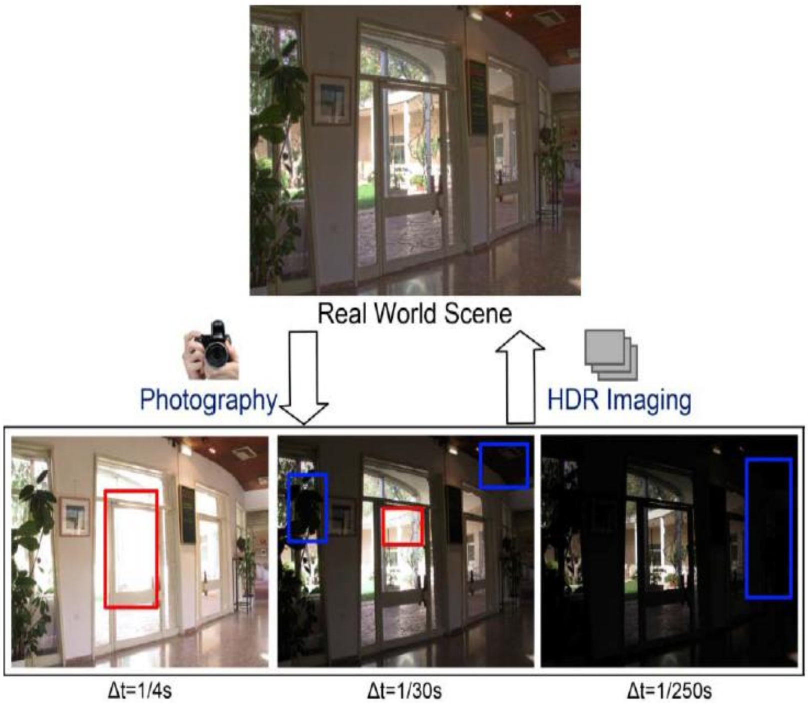


Figure 1.7: An HDR image using multiple LDR images [4]

1.3.1 Dynamic Range

A scene's dynamic range can be described as the range between the lowest light intensity and highest light intensity. It is also known as scene contrast. The dynamic range that can be perceived by the Human Vision System (HVS) is too large. The complete range of intensity of light perceived by HVS is from the light of star as lowest and light of sun as highest. The range is in the orders of magnitude of 10. Also, if there is any change in the lighting condition, the human adapts to it very quickly. But the dynamic range of the traditional imaging devices is only in the order of magnitude of 2 in a single exposure. This is the reason behind the loss of information in the areas which are either dark or bright. These areas are known as saturated areas [4].

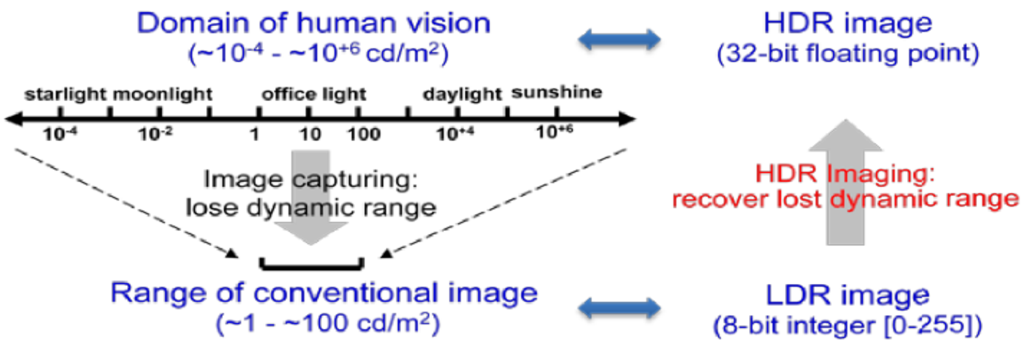


Figure 1.8: The range of human vision system compare to LDR images [4]

1.3.2. High Dynamic Range Acquisition

In order to recover a scene of real world different methods for HDR synthesis can be used with different methods of acquisition, which are defined below:

- **Single Image Capture:** We can capture the HDR image by the use of a single shot. In this we capture a single LDR image and with the use of any special hardware, convert it into an HDR image. One such method is Gradient camera method. In this method the gradients are captured in place of pixels intensities. In this way the dynamic range is increased [4].
- **Single Device Multiple Image Capture:** In this we capture multiple LDR images of the same scene using a single device. One such method is Exposure Bracketing, which is the most popular method, in which we capture multiple LDR images of the same scene with a single device with different exposure time and then fusing them to recover the original scene [4].
- **Multi-Device Capture:** In this we capture multiple LDR images of the same scene with different devices .In this we use prisms or beam filters [4].

1.3.3. High Dynamic Range Display

As we know that there is a problem in the acquisition of HDR image using the conventional devices due to their hardware limitation, there is also a problem while displaying the images with high dynamic range on the conventional devices. The traditional display devices cannot display the HDR images because the traditional display devices have the dynamic range, which is very low in comparison to the dynamic range of HDR images. In general the devices which are used for displaying the images like monitors, they use the RGB color model for displaying the images. As we know that they use 24 bits per pixel means 8 bits for every color channel which have 255 different values for the intensity while the HDR images have 32 bits for every color channel and it will have various intensity values. Therefore, to display the HDR images on the traditional display devices, there is a need of conversion from HDR images into the LDR images before they can be presented on the conventional display devices. For the conversion of the HDR image into a LDR image, HDR tone mapping methods are used [4].

1.4. Tone Mapping

High Dynamic Range reduction or Tone Mapping techniques are used to map the HDR images to low dynamic range displays because they have very low contrast. When the HDR image is acquired by using different acquisition methods, then there is a need of conversion of these HDR images into LDR images so that they can be displayed on the traditional display devices [5].

The Tone mapping methods for the reduction of dynamic range are broadly classified into two broad categories, i.e. Global and Local tone mapping operators [5].

1.4.1. Global Tone Mapping Operators

The Global Tone Mapping operators also known as spatially invariant, apply the same function to all the pixels of an image, i.e. one input value results in one and only one output value. They can be a power function, a logarithm, a sigmoid, or a function that is image dependent. Global tone mapping methods are suitable for scenes whose dynamic range corresponds approximately to the dynamic range of the display device, or lower. But when the dynamic range of the scene is larger than the display device, then global tone mapping method will compress the dynamic range of the scene too much, which result in a loss of contrast and detail visibility. Global operators are computationally very simple and preserve the intensity orders of the original scenes thus avoiding halo artefacts. Global tone reduction operators are suitable for video processing [5].

1.4.2. Local Tone Mapping Operators

The Local Tone Mapping Operators also known as spatial variant, apply different functions for different spatial pixel positions, i.e. one input value can result in more than one output value depending upon the pixel position and surrounding pixel values. Because there is a loss of contrast and detail in the Global Tone mapping method, local tone mapping methods are used to improve the local contrast, which improves the detail visibility of the image while the image is also compressed so it can be displayed on the display device [5].

Figure 1.9: Global Tone Mapping and Local Tone Mapping [5]

1.5. Different Metrics used for Comparison

1.5.1. Modified Peak signal-to-noise ratio (MPSNR)

The modified form of Peak-signal-to-noise ratio is considered as MPSNR. The quality measurement will be enhanced by using the MPSNR value. To measure the quality of the original image and reconstructed image, PSNR is used. PSNR is generally used for normal RGB images, but for the HDR images MPSNR is defined which will evaluate the quality of the original image and tone mapped image. MPSNR is used for the measurement of quality of reconstruction. It is described in the unit of logarithmic decibel. If the value of MPSNR is high, means the reconstruction is of good quality [6]. MPSNR can be defined by the equation 1.3 [6].

$$MPSNR = 10 \times log_{10}(\frac{col \times 255^2}{MSE}) \tag{1.3}$$

where col the luminance channel of the image and MSE is Mean Square Error.

1.5.2. Mean square error (MSE)

It is the aggregate of squared error between the reconstructed and the original image. It can be defined as a risk function which is related to the expected value of quadratic loss [7]. It can be defined by equation 1.4 [7].

$$MSE = (\frac{1}{MN}) \sum_{i=1}^{M} \sum_{j=1}^{N} [O(i,j) - C(i,j)] \tag{1.4}$$

where $O(i,j)$ is actual image and $C(i,j)$ is the reconstructed image. M and N are the dimensions. If the value of MSE is less means error is less.

1.5.3. Signal-to-noise ratio (SNR)

In an image, visibility of an object depends on the brightness of its surroundings. It is visible if its brightness is different from its surroundings. It means that the noise in the image must be overcome by its contrast. The contrast that a human eye can detect is in range, from 0.5% to 5%. It means that humans can differentiate between 20 to 200 gray shades from blackest black to whitest white. Signal-to-noise ratio can be defined as the ratio of contrast to the standard deviation of the noise. In mathematical terms, it is the ratio of signal power to power of noise [8]. Its unit is decibel. SNR is defined by equation 1.5 [8].

$$SNR_{db} = 10log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \tag{1.5}$$

where P is the measure of power.

1.5.4. Mean absolute error (MAE)

It is used to measure that how close the reconstructed image to the original image. It is the average of absolute errors. It is defined by equation 1.6.

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |e_i| \tag{1.6}$$

where $|e_i| = |f_i - y_i|$ and f_i is the reconstructed image and y_i is the original image.

Chapter 2

Literature Review

There are different local and global tone mapping techniques that have been proposed in the past. As the tone mapping methods evolve, initially only the global tone mapping operators were introduced which were degrading the quality of the tone mapped image, so later local tone mapping operators were invented. Different tone mapping techniques have been described in this section.

2.1. Global Tone Mapping Techniques

Tumblin *et al.* [9] introduced the first tone mapping technique which is considered as a reference in the field of tone mapping. They inspire from the fact that the various image synthesis algorithms are not able to differentiate night and day, which are easily understandable from the human. Work is started on it so that the actual scene can be displayed on the output device. It's a global tone mapping algorithm based upon the human vision's mathematical model. For dark scenes it is not suitable. It is only applicable on gray scale images.

Tumblin *et al.* [10] proposed a tone mapping method so that the low dynamic range devices can display the high contrast images. For this, many instances of *low curvature image simplifier* (LCIS), which is a partial differential equation is used, based on anisotropic diffusion. The image is broken into multiple smoother regions by every LCIS. Every region is bounded to a parameter K which is used to control LCIS region size, also the complexity of the boundary and also bounded by gradient sharpen discontinuities. By using these K values, LCIS creates a set of simpler images and also a set of image differences of details, large features and boundary. This method produces tone mapped images which have their details preserved. In this technique the details are removed from the image so that sharp regions can be separated by sharp boundaries. The details have been recovered later by subtracting the LCIS-smoothen image from the input image.

Reinhard *et al*. [11] presented a method for the mapping of real world scenes with high dynamic range on the devices of low dynamic range. In the proposed methodology, the tone mapping methods which are introduced earlier are used. A

Zone System is used to implement the tone reproduction operator [12]. Zone System is used for the improvement of the final output, which is a Roman numeral associated with the luminance range of the scene and also with the reflectance of print. In total, 11 print zones are in existence, which are in the range from pure black (Zone 0) up to pure white (Zone X). Initially the tone mapped image‘s tonal range is set on the base of scene’s key value. The log-average luminance is used as an approximation for the scene’s key for this purpose. Then the dodging and burning, which is automatic, is applied. It is applied on a complete area which is bounded with large contrasts. The final output is a tone reduced image.

Mantiuk *et al.* [13] presented a method that can minimize the contrast and dynamic range of HDR images to display them on output devices. In this technique, the distortions in contrast, are weighted by the Human Visual System according to their predicted visibility. Then the minimization of distortions is done by using a display model, which apply the constraints. The dynamic range is minimized by using quadratic programming and image statistics. The contrast probability function, which is conditional, is computed by the division of input HDR image into equally sized N no. of bins and a center is denoted for each of these. This is done to know the number of pixels that can be affected, by any tone mapping operation. The selection of N is done on the criteria that the gap between the bins should be equal to 0.1. Following that histogram is evaluated for each of the contrast values. By using this set of histograms, conditional probability density function is obtained. Following that the tone mapping function is applied and the output is a tone mapped image with minimum distortions.

Shan *et al.* [14] presented a tone mapping operator in which, on small windows which are overlapped, local linear adjustments are performed across the entire HDR image. The linear adjustment is applied locally by each window which preserves the radiance values monotonicity. On each overlapped window, a global optimization is applied to satisfy the local constraints defined on them. For effectively reducing the high contrast and for preserving details, as guidance, local constraints are used. The image structure can be preserved by this method even for the HDR images in which either abrupt radiance change occurs or smooth salient transitions occur. First the computation of radiance map in low dynamic range is done using the radiance of

HDR image. Then the local structures of the image are retained accurately. For this, neighbour of the pixels is considered in local region and local linear function is applied and reconstruction of image is done and optimization is applied. This method is effectively reducing the global contrast and preserving the details.

Meylan *et al.* [15] presented a technique to render HDR images, based on human visual system's (HVS) local and global adaption. This method operates upon Retinex model which is centre-surrounded. In this method first an adaptive filter is used. The shape of this filter follows the high contrast edges of the image to reduce the halo artefacts which is a common problem in most local tone mapping techniques. A sigmoid function is used to reduce the gray-out. In this method, the luminance channel of the image is processed by using principal component analysis (PCA) to reduce the chromatic changes. In this method the HVS is considered so that chromatic and achromatic data can be treated independently. In the first step dynamic range is compressed using global adaption of HVS. The average luminance is computed. In the next step local adaption of HVS model is used, in which surround-based Retinex method is used and the adaptive filter is used to remove the halo artefacts. The sigmoid function is used to remove the gray-out. This method produces high quality tone mapped images without halo artefacts and gray-out and produce good results in dim areas.

2.2. Local Tone Mapping Techniques

Durand *et al.* [16] presented a technique for the tone reduction in which the contrast is less and details are insured. In this technique, the input High Dynamic Range image is decomposed into layers i.e. base layer and detail layer. The reduction of contrast is done only on base layer and detail layer remains untouched. In this way the preservation of details are ensured. For the decomposition of the image, a non-linear filter which is also edge preserving is used i.e. Bilateral Filter [17]. After the decomposition a log function is applied on the base layer and in the final stage the contrast reduced base layer and the details layer are merged to get the final tone mapped image. First the luminance channel is extracted and then bilateral filter is applied. After then log function is used to reduce the contrast of base layer. The tone reduced images are of good quality and has their details preserved.

Drago *et al.* [18] proposed a method for converting the high dynamic range images to low dynamic range images. In this local tone mapping method luminance values are compressed using logarithmic compression. To vary the logarithmic bases adaptively a bias power function [19] is used which ensure the details preservation and contrast reduction. The manipulations are done in gamma correction procedure so that contrast can be improved in dark areas. First the luminance channel is separated from the image and then the logarithmic mean is computed. In this method, the luminance channel of every pixel and the image maximum luminance is divided by the luminance of world adaption and finally multiplied by the parameter which is provided by the user. This parameter is the maximum luminance capacity of the displaying device. The bias power function is applied so that the compression of high values can be adjusted and also details in dark areas can be visible. The tone mapping function is defined using the equation (2.1) in which L_d is used for the computation of displaying value for every pixel.

$$L_d = \frac{L_{dmax}}{log_{10}(L_{wmax} + 1)} \cdot \frac{\log(L_w + 1)}{\log\left(2 + \left(\left(\frac{L_w}{L_{wmax}}\right)^{\frac{\log(b)}{\log(o.5)}}\right).8\right)} \tag{2.1}$$

Where L_{dmax} is the maximum luminance value for the intended displaying device. L_w is for luminance component of every image pixel. L_{wmax} is the image maximum luminance. The value of b can be varied according to scene and it can be varied by the user. b is defined as bias power function for varying the logarithmic base adaptively and for the adjustment of the contrast. In the final tone mapped image, gamma correction is applied so the dark areas will be displayed effectively.

Ashikhmin [20] presented a tone mapping technique to reduce the high dynamic range image to low dynamic range image. This method relies on the human visual system (HVS) but not actually implements the conceptual model of HVS. This is a three step technique. At the beginning, estimation of the local adaption luminance at each pixel of the image is done. Following that, a simple function to the values which are obtained earlier, is applied so that the dynamic range can be compressed. At the end, re-introduction of the details is done in the image, so preservation of the details can be accomplished. In the tone mapping algorithm the luminance channel is extracted and a Gaussian pyramid is structured. After this the local adaption luminance is calculated. After that the tone mapping function is applied and final pixel luminance is computed. The color image is reassembled and the gamma correction is applied to get the desired pixel values that can be easily displayed on the display system.

Fattal *et al.* [21] proposed a dynamic range reduction technique in which they use the gradient field of image luminance by reducing the magnitude of large gradients. To obtain the tone mapped image a Poisson equation is applied on the gradient field which is modified earlier. In this technique they first identify the large gradients and then reduce their magnitude and also preserve the details. They use the logarithmic of the luminance and then apply the Poisson equation so that a tone mapped image is produced. This method predicts that the Human Visual System (HVS) cannot sense the luminance which is reaching to retina, but it responds to changes in the local intensity. If there are any changes done in the luminance of HDR image, large magnitude luminance gradients will rise. Fine details, for example texture will correspond to gradients of very smaller magnitude. Therefore, at multiple scales large gradients are obtained, and also their magnitudes are attenuated and also their direction is kept unaltered.

Farbman et al. [22] presented a new technique of tone reduction in which they split the image into multiple scales. Generally the image is decomposed into a base layer which contains very large differences in intensities and a detail layer which contains small details of the input image. This is done by a bilateral filter in most of the tone mapping methods. In this technique a new edge preserving filter is used which is based upon weighted least squares (WLS) [23] for image decomposition. It suits for the augmentation of images and also for extraction of multi-scale details. In this first the HDR image is decomposed into a base layer and multiple detail layers using WLS edge-preserving operator. Then the down sampling of base layer is done. The tone mapped image is obtained by merging the down sampled base layer and detail layers.

Qian *et al.* [24] presented a tone mapping method for displaying the high dynamic range images on display devices having low dynamic range. It is based on Contrast Limited Adaptive histogram Equalization (CLAHE) technique. In this method the image is splitted and merged to segment the image luminance. The CLAHE is applied on each segment having different clip limit so that the visual range can be extended. This method is applied only on the luminance channel. The HDR image is a RGB image having float values and it is linear to absolute luminance. The HDR image is transformed into CIE XYZ color space. Then the log average luminance is computed. Then the scaled luminance is calculated. This is done so that, on which regions CHALE can be applied, is determined. Now the image is segmented into small regions using region growing method CLAHE is applied to each local region having a different clip limit. After this merging technique is applied so that the adjacent regions will not have the same properties. In the final step, XYZ color space is converted back into RGB color space and a high quality tone mapped images is obtained.

Li *et al.* [25] presented a tone mapping technique which relies on statistical and spatial information. In this technique initially the image is divided into two layers i.e. base layer and detail layer. The base layer shows the smooth details and the detail layer represents the fine details. On the base layer histogram adjustment, which is Statistical- based, is applied. To obtain the detail layer, a spatial filter is enhanced adaptively based on the mapping function which is used for base layer. The first step of this step is the decomposition of HDR image into i.e. base layer and detail layer. Base layer consist of bright and dim component and the detail layer consist of local details. The decomposition of HDR image is done using bilateral filter [17] which is a edge preserving filter. Histogram is applied on the base layer so that global mapping function can be derived and also a gain map is derived. To preserve the visual details, the detailed layer is enhanced adaptively by using the slope of the function used for global mapping. The detailed layer after the enhancement is merged with base layer. The tone reduced image is obtained by applying the gain map on the detail-enhanced image.

Rienhard *et al.* [26] presented a method for the mapping of HDR images on devices with limited dynamic range. For this they used photoreceptor's computational model. To overcome the problem of dynamic range reduction, Human Visual System (HVS) apply various components of adaption. In this particular methodology a photoreceptor's adaption model is used, which is the receptor's automatic adaption to the illumination. The potential V which is derived by cones on the basis of intensity I is defined by equation 2.2.

$$V = \frac{I}{(I+\sigma(I_a))} V_{max} \tag{2.2}$$

$$\sigma(I_a) = (f I_a)^m \tag{2.3}$$

Where $\sigma(I_a)$ is the photo-receptor adaption and I_a is the adaption level and f and m are constants. The value of m can be in the range of 0.2 to 0.9 and the value of f = 1 will produce results of high quality. These two parameters m and f can be adjusted by user and controls the contrast and intensity. The equation (2.2) which is defined above is exercised on each of the three color channels independently. The tone mapped images as output, do not have the halo artifacts.

Duan *et al.* [27] proposed a comprehensive operator based on the tone reproduction curve for visualizing the HDR images. For a same image, different users can use it according to different preferences. That's why the Tone mapping method had to be interactive and also should be fast, so that the users can adjust according to mapping parameters and the output can be visualize instantly. Also there should be some parameters which can be adjusted by the users. To satisfy the following requirements a comprehensive mapping technology based on the tone reproduction curve is developed. In this operator two parameters can be varied, in which first is used for the control of overall brightness and other is used to adjust the contrast and also the details of the final tone mapped image. Software has been used for the visualization of HDR image which implements the tone reduction operator. In this method, first adaptive luminance mapping is done for the compression of luminance of HDR image. In this step, a parameter α is used which controls the overall brightness of tone mapped image. In the next step, adaptive histogram adjustment is done on the output of first step. For this, the image is divided into intervals and compression is done on the pixels which are falling in the same interval to obtain same display value. The quantization has been used for compression. The parameter which is controlled by the user is β. If the value of β=0, it will have a linear adjustment and if value of β=1, it will have histogram equalized adjustment. So the value of β is in the range of 0 and 1. This operator works on tone reproduction curve and is providing high quality tone mapped images.

Gu *et al.* [28] presented a technique in which, for the decomposition of image, a new filter is proposed which is also edge-preserving. The image which is filtered contains all means everything and the salient edges which are local are also preserved. In this tone reduction technique, the image is decomposed into multiple layers using the proposed filter i.e. base layer and three details layers. The filter is used for multi-scale decomposition assumes three things: (a) the preservation of local areas are ensured by base layer, (b) the detail layer contains all the gradient information which is not zero and (c) all the edges, in the local window, are large gradients relatively. For the compression of the detail layers, a function is used. The images which are reproduced are of good quality and have better visualization.

Kim *et al.* [29] presented a tone reduction algorithm in which, a decision method which is based on a new k factor and highlight factor of compression are used for the enhancement of the naturalness and the quality of appearance of the HDR images which are rendered. For the preservation of local contrast, the retinex method is considered as the better local operator, but the method does not give good appearance of the image and contrast is also not good in dark areas in some cases. In this method, the decision method which is based on the k factor is proposed because in retinex algorithm, it is considered as one of its parameters. This enhances quality and in the dark areas also the details are more distinguishable by the use of highlight operator for compression.

2.3. Combination of Global and Local Tone Mapping Techniques

Tian *et al*. [30] presented a method which is based on segmentation to display HDR images on the devices with limited dynamic range. In this method, the image is segmented into small regions and adaptive contrast is carried out and also the brightness is adjusted using the tone reduction operator which is global in nature. This is done in local regions so that the brightness and local contrast can be reproduced and also to ensure the better quality. For the elimination of the boundary artifacts which can occur due to the process of segmentation and also for the elimination of noise which can be introduced while decreasing the local contrast, a weighting scheme is used. For the segmentation of an image, various methods have been presented; one of them is used in this paper. The segmentation method should be such that can divide the image in the form of object-based regions. Also there should be no overlapping between the regions. After the segmentation process, local tone mapping is applied on each local region. In this step the main focus is towards the reproduction of brightness and contrast of each region. For this HALEQ [31] method is used. In the following step, the avoidance of boundary artifacts is done by the use of a weighting scheme. Here, for every pixel of image, final tone mapped pixel value is obtained by calculating the weighted average. Final output is a tone mapped image with better contrast and brightness.

Duan *et al*. [31] proposed histogram adjustment methods to reduce the dynamic range of HDR image. In this technique, first a global tone mapping operator which is based on histogram adjustment, is presented for reproduction of global contrast for HDR images. After that the images are segmented and contrast adjustment is carried out adaptively using global tone mapping operator on the local regions so the local contrast can be reproduced and good quality can be ensured. In this method, first the logarithmic function is used for the compression of luminance of HDR images. A parameter τ is used to control the brightness of the mapped image. If the value of τ is high the mapped image will be darker and if the value of τ is low then mapped image will be brighter. In this way the global tone mapping operator is defined. In this method a tone mapping operator which is based on Adaptive Local Histogram Adjustment (ALHA) is used. In this first the logarithmic mapping is applied on the HDR image to determine that on which local regions HALEQ can be applied. Now the image is segmented into local areas and HALEQ is applied on each area so that tone mapped image will be of good quality and preserve the details.

Lee *et al*. [32] introduced a local tone reproduction algorithm, in which K-means algorithm is used to segment the HDR image and for every segmented region, automatically set display gamma parameter is used. In the proposed method the luminance of the input HDR image is computed, which is the radiance map. This is obtained using low dynamic range images which are acquired by various exposure settings. Then using the K-means algorithm, the image is decomposed into multiple regions. This is done in accordance to luminance which is bilateral filtered. By using the average value of each region, automatically the display gamma values are set. Preceding that, by using a tone mapping algorithm which is linear, having adaptive gamma value, the tone of HDR is reproduced. The resultant tone mapped image has a good visual quality and also has a good local contrast. First HDR image is generated using 3 LDR images each having different exposures time. In this method, the luminance component is extracted from HDR radiance map by using a bilateral filter [17]. After that this luminance component is mapped by the use of a logarithmic function. This is considered as initial mapping which is global. This global mapping luminance is used as an input for the K-means block of clustering. On every local region, the luminance is mapped of the scene of real world with HDR to the limited dynamic range device's luminance applied adaptively. In this method the input image is segmented into different number of local regions, which is according to the initial global mapping luminance. By the use of K-means algorithm [33], an image is segmented into K-cluster regions in the block of K-means clustering. The assignment of each pixel in K-means block of clustering is done to the cluster according to the mean of pixels which are presented in that cluster. For automatically setting the gamma values which are used for correction of color, K clusters mean vector is used. The final tone reduced image is of better quality.

Tian *et al.* [34] proposed a local tone mapping method which is very fast for the display of HDR images. The methods of local tone mapping provide a tone mapped image with good contrast and also details, but they are slow in execution. In this technique, this problem is solved by a parallel algorithm which can be constructed on Graphics Processing Unit (GPU), so that computational efficiency of high order can be achieved. In the proposed technique, the HDR image is decomposed into rectangular blocks which are non-overlapped and contrast and brightness is reproduced on every block simultaneously. This process is accomplished by the use of a global tone reproduction operator which is highly parallel. Initially the input HDR image is segmented into blocks which are rectangular and independent and on these blocks the HALEQ [31] is conducted. In the preceding stage, information which is spatial is incorporated in the different blocks so that the final result can be obtained for a pixel and also for the avoidance of the boundary and halo artifacts. In the next step local contrast has been enhanced. The tone mapping using GPU takes less computation time as compared to other local tone mapping techniques.

Chapter 3

Problem Statement

In this particular chapter, the gaps which are there in the current work; the problem statement, the objectives which are to be achieved and method for achieving these objectives are discussed.

3.1 Gap Analysis

In the Literature Review, we have discussed the different techniques of tone reduction of HDR images in which some are global and some are local methods of tone mapping. In the existing work following gaps are there:

1) The tone mapped images produced by the current techniques did not preserve the details and also the quality of the images is not so good, so there is a need of new methods of tone reduction which can preserve the details and also improve the quality.

2) There is very less work has been done in the field of tone mapping, and also the hardware devices for displaying the HDR images are quite expensive, so there is need of more methods of tone reduction.

3) In most of the existing tone mapping methods, there is problem of halo artifacts that is introduced during the reduction of dynamic range, so there is a need to remove these artifacts.

4) While generating the HDR image using multiple Low Dynamic Range images, if there is any movement of any person or thing, then there is introduction of ghosting artifact, so the removal of such ghosting artifacts is also needed.

3.2 Problem Statement

Various methods of tone mapping have been already presented for reducing the dynamic range of HDR images in which some are based on the decomposition of HDR images into multiple layers and then reducing the contrast of each layer, some are based on the reduction of contrast by using log functions etc. But in most of the techniques there exist some problems like in most of the global methods of tone mapping, the dark areas or bright areas are not properly highlighted and in the local methods of tone mapping, generally the halo artefacts are introduced across the boundaries or the edges.

In order to avoid these problems like the boundary artifacts and to improve the quality of contrast and also the brightness of tone mapped image a tone mapping method can be introduced in which the use of bilateral filter and a bias power function can be used for the enhancement of image quality and also the tone reduced image without any artefacts can be obtained.

3.3 Objectives

1) To study different techniques of global and local tone mapping.

2) To propose a method of tone mapping using bilateral filter and a bias power function.

3) To implement the technique using the proposed method.

4) To test and validate the output of proposed method using different comparison metrics.

3.4 Methodology

1) Literature Review.

2) Present the method by the use of different image processing techniques and also by the use of different functions of dynamic range reduction.

3) Implementation of the desired method is as follows:

(3.1) Separate the luminance channel from the input HDR image.

(3.2) Decompose the luminance channel into 2 layers i.e. base layer & detail layer by the use bilateral filter.

(3.3) Computation of logarithmic mean and adjustment of contrast using bias power function.

(3.4) Apply the tone mapping function.

(3.5) Recompose the tone reduced base layer and detail layer.

(3.6) Apply the gamma correction to improve the contrast of tone reduced image.

(3.7) Test and validate the results using different comparison metrics.

Chapter 4

Proposed Methodology

In this chapter the tone mapping method for the reduction of the dynamic range of HDR image is included. In our method we have used MATLAB R2013a for the implementation. The previous versions of MATLAB did not support the HDR images. MATLAB is used because it provides an environment where computation is quite easy and also programming can be done in an efficient way. As we discussed that most of the local tone mapping methods which are proposed earlier, the image is divided into different layers and contrast of each layer is reduced. In the final output image all the contrast reduced layers are recomposed. It introduces the halo artifacts in the tone mapped image. In the proposed tone mapping method the high dynamic range image is decomposed by the use of bilateral filter into 2 different layers. It only reduces the contrast of the base layer by the use of a bias power function and mean of logarithmic values and detail layer is remained untouched. In the final output image the contrast reduced base layer and detail layer are recomposed. In this section a brief introduction about the MATLAB and the local tone reduction method has been presented.

4.1. Overview of MATLAB

MATLAB which is named as matrix laboratory is an environment of numerical computing in multi-paradigm. It is considered as a 4^{th} generation language of programming. By using MATLAB, the manipulations of matrix can be done easily, data and functions can be plotted, algorithms can be implemented, various user interfaces can be created and also interfacing can be done with the programs which are implemented in different programming languages like JAVA, C++, C and Python. The chief scientist of Math Works Inc. Dr. Cleve Moler had written the first version of MATLAB in 1970’s. It is developed for the students so that they can access the LINPACK and EISPACK projects without any need of learning the FORTRAN language. It is used for the courses like numerical analysis, matrix theory and linear algebra. MATLAB can be defined as matrix software because the basic element of MATLAB is a matrix in which there is no need pre-dimensioning. Many computing problems which are technical can be easily solved by using MATLAB. In many institutions MATLAB is used in Research work by the students. MATLAB is also very useful in the field of image processing since it provides inbuilt Toolboxes like HDR toolbox, image processing toolbox, toolbox for neural networks, signal processing etc. Various functions have been provided in these toolboxes, which can be used for different purposes [35].

4.2. Different Techniques used in proposed method

4.2.1. Bilateral Filter

Tomasi and Manduchi [17] introduced the bilateral filter which is an alternative to anisotropic diffusion. The bilateral filter is a non-linear filter which produces the output that is the average weight of the input. They use Gaussian filtering and a spatial kernel f. To decrease the weight of the pixels that have large intensity difference, function g is also used which is an edge stopping function. For a pixel x the output of the bilateral filter is defined by equation 4.1 [16].

$$j_x = \frac{1}{k(x)} \sum_{p \epsilon \Omega} f(p-x) g\left(I_p - I_x\right) I_p \tag{4.1}$$

Where $k(x)$ is normalization term in equation (4.2) [16]

$$k(x) = \sum_{p \in \Omega} f(p-x)\, g\left(I_p - I_x\right) \tag{4.2}$$

Here j_x is the filtered image, I is the original input image and p are the coordinates of the current pixel which is to be filtered. In the spatial domain they use Gaussian for f and in the intensity domain they use Gaussian for g.

4.2.2. Bias Power Function

For the adjustment of contrast, a "bias" power function, which was presented by Perlin and Hoffert [19], is used. The bias power function is necessary to adjust the compression of high values and also for the preservation of details in dark area. The bias power function is defined as equation (4.3) [17]:

$$bias_b(t) = t^{\frac{\log(b)}{\log(0.5)}} \tag{4.3}$$

Where $bias_b$ is the power curve which is defined over the unit interval. The value of b can be varied.

4.3. Architecture of the proposed method

The process of the proposed tone mapping technique is categorized into 6 different steps. The architecture of the proposed tone mapping technique is shown in figure 4.1.

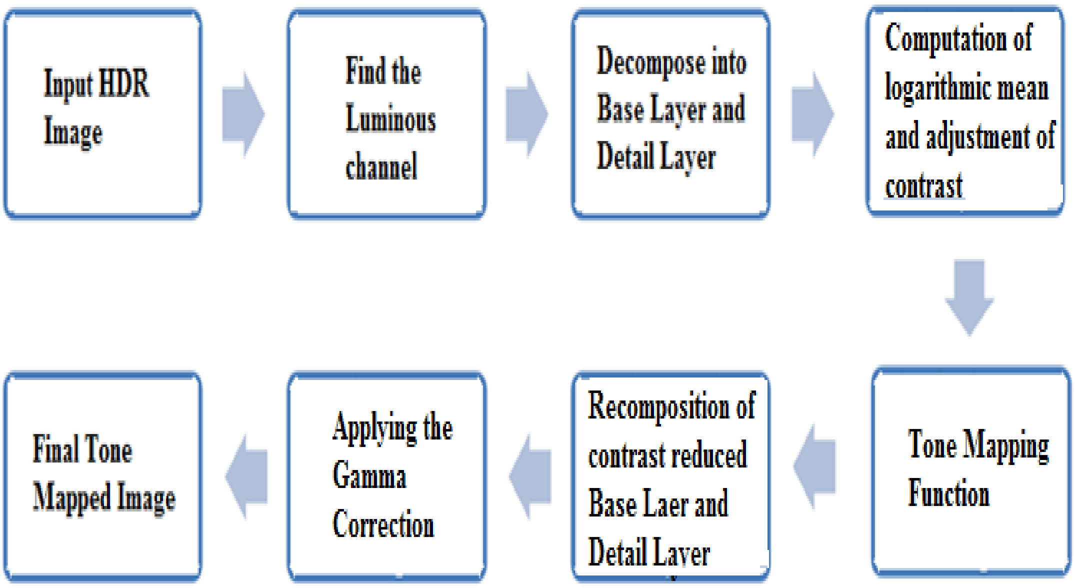


Figure 4.1: Architecture of the Proposed Tone Mapping Method

The steps are described below:

4.3.1. Find the Luminous channel

In this method first luminance channel is separated from the high dynamic range image to retain the color information. The HDR image which is given as input is initially in the RGB color space. To extract the luminance channel we need to convert it into YC_bC_r color space from the RGB color space. The Y channel is used for luminance in the YC_bC_r color model which is obtained by using the equation (4.4).

$$L = 0.2126 * R + 0.7152 * B + 0.0722 * G \tag{4.4}$$

Where L is luminance channel and R, G, B are color channels of the image pixels.

(a) Original HDR image **(b) Luminance Channel**

Figure 4.2: Separation of Luminance Channel

4.3.2. Decomposition into Base Layer and Detail Layer

In this step, the luminance channel is decomposed into two layers i.e. base layer and a detail layer. To decompose the image an edge preserving filter which is non-linear filter is used, i.e. bilateral filter. For the decomposition of the luminance channel by the use of bilateral filter, first the log function is applied on the luminance channel. After applying the log function, on the output, bilateral filtering function is applied. In the bilateral filter, two parameters are used, i.e. Sigma Spatial and Sigma Range which are used for the specification of the standard deviation of the space and range Gaussians, respectively. Sampling the Spatial and Sampling the Range are used for the specification about the amount of down sampling which is used in the approximation. If the value of these parameters is high, it will use less memory but are also less accurate. By using this bilateral filter, the base layer is extracted from the image and on that base layer the log operation is performed. Detail layer is obtained by dividing the input image and base layer. After the decomposition only the base layer is used for contrast reduction.

(a) Base Layer **(b) Detail Layer**

Figure 4.3: Decomposition of Image in two layers

4.3.3. Computation of logarithmic mean and adjustment of contrast

To determine the brightness of the output image, the lighting characteristics of scene are used. Therefore it is important to find a scale factor from the image luminance for output image brightness. In the modern cameras there are different options available which can be used for setting the exposure, like center-weighted. In the proposed method, two methods are used. If the scene is static then in this step we calculate the logarithmic mean of luminance of the base layer which is based on the luminance of the pixels. After that the center-weighted scaling factor is also calculated which is used for tone mapping which is interactive. The center-weighted scaling factor is used for the calculation of the logarithmic average which is of the region that is centered on a pixel.

In this tone mapping function adaptive adjustment is done of logarithmic base which is dependent on radiance of every pixel. The luminance values which are there in the scene are interpolated from $\log_2(L)$ to $\log_{10}(L)$. By doing this, in the areas which are dark or medium, good contrast can be achieved and also preservation of details can be done. At the same time luminance values which are high can be compressed. For the value of $\log_k(L)$, where $k<2$, it will be difficult to adjust in sharp exposure. If the value of $\log_k(L)$, where $k>10$, the compression of luminance doesn't change too much but too much contrast of the image will be lost.

4.3.4. Tone Mapping function

In the tone mapping function, the data which is used as input is converted into float values. Every pixel's luminance component L_{wa} and scene's maximum luminance $L_{\max wa}$ are divided with the world luminance of adaption L_{wa}. After that it is multiplied by the factor which is used as exposure factor controlled by the user. In this method, for each pixel, the output displaying value L_{dis} by equation (4.5) [20] can be computed.

$$L_{dis} = c_2 * \frac{\log(1+L_{wa})}{\log\left(2+8*\left(\left(\frac{L_{wa}}{L_{\max wa}}\right)^\wedge c_1\right)\right)} \tag{4.5}$$

where

$$c_2 = (L_{dis\_max}/100)/(log_{10}(1 + L_{\max wa}))$$

$$c_1 = \log(b)/\log(0.5)$$

$L_{dis\_\max}$ is a scale factor which is used to adapt the output tone mapped image to its intended display. In our method L_{dis_max} = 100 cd/m^2 is used, because it is the reference value for CRT displays. $L_{\max wa}$ is the ratio of the maximum luminance of the scene L_{max} and L_{wa} which is the world adaption luminance. The value of the bias power function b can vary from 0.70 to 0.95 for good quality images. In our method the value of b is 0.90.

4.3.5. Recomposition of contrast reduced Base Layer and Detail Layer

In this stage the contrast reduced base layer and detail layer have been recomposed and a u high quality tone mapped image has been obtained by reconstructing the RGB image by using the luminance channel. After applying the tone mapping function the contrast reduced base layer has been obtained. Since it is only the luminous channel so it is only a 2-D image and we need an LDR image with RGB channels. By using the luminuous channel the conversion is done from 2-D to 3-D image.

(a) Input HDR Image **(b) Tone Mapped Image**

Figure 4.4: Result after applying the new Luminuos Channel

4.3.6. Applying the Gamma Correction

In this step the Gamma correction is applied on the tone mapped image so that non-linearity of the display devices can be compensated. For the non-linear display devices, a gamma coefficient γ=2.2 is used in our method. In our proposed method the gamma correction is applied on RGB values after the tone mapping. If the HDR image contains the dark areas, their appearance is not properly visible in the tone mapped image, so to improve the contrast in the dark areas of the tone mapped image, the gamma correction is applied.

(a) Tone Mapped Image before Gamma Correction **(b) Tone Mapped Image after Gamma Correction**

Figure 4.5: Final result after the Gamma Correction

Chapter 5

Experiments and Results

The results of the experiment shows the tone mapped images, which are obtained by applying the proposed method of tone reduction on different high dynamic range images. In this section, different results have been shown of tone reduced images, which have been produced by applying our method. Also we have compared our results with two previous methods of tone mapping. We have compared our results with the two techniques based on the comparison metrics which are PSNR (Peak Signal-to-Noise ratio), MSE (Mean Squared Error), SNR (Signal-to-Noise ratio) and MAE (Mean Absolute Error) in table 1.

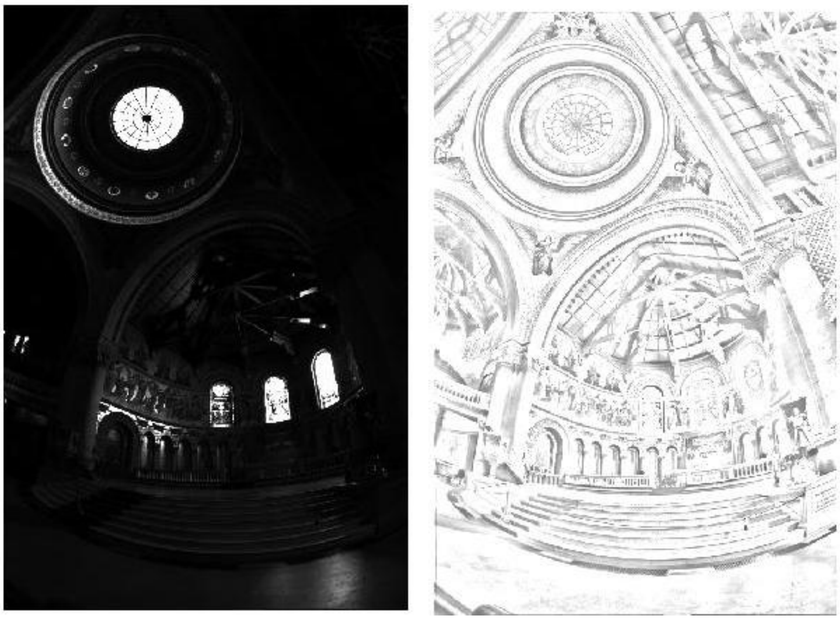
5.1. Result of memorial.hdr image

The memorial.hdr image is taken as input. Its luminance channel has been separated. The input image and its luminance channel are shown in figure 5.1.

(a) memorial.hdr (b) Luminance Channel

Figure 5.1: Separation of Luminance Channel of Memorial.hdr

Now the image is decomposed into two layers i.e. Base Layer and Detail Layer. The two layers are shown in figure 5.2



(a) Base Layer **(b) Detail Layer**

Figure 5.2: Decomposition of image in Base Layer and Detail layer

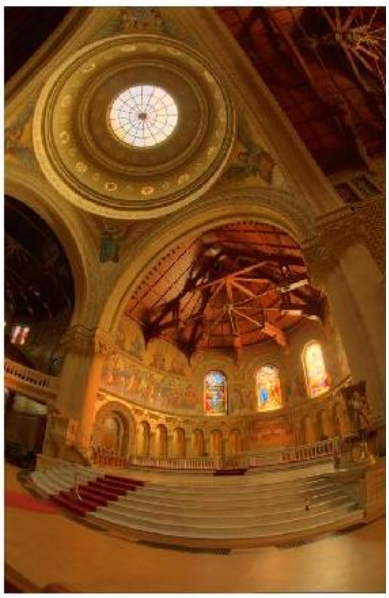
Now the tone mapping function has been applied on the base layer and the final tone mapped image has been reconstructed by merging the contrast reduced base layer and detail layer. After that gamma correction is applied to obtain the final tone mapped image. Result after applying the new luminous channel and the result after applying the gamma correction is shown in figure 5.3.

(a) Before Gamma Correction **(b) After Gamma Correction**

Figure 5.3: Result of proposed method before and after gamma correction

We have compared our results with two previous methods of tone reduction. The results of our method and the two methods defined by Durand and Drago are shown in figure 5.4.

(a) **Tone mapping using Durand TMO (b) Tone mapping using Drago TMO**



(c) Tone mapping using proposed method

Figure5.4: Comparison of our method with two other methods

As from the results it is clearly visible that the tone mapped image which is obtained by using our method is superior to other methods. The contrast and details are preserved in our tone mapped image. The dark areas are clearly visible in the tone mapped image. Also the comparison metrics are also improved which are shown in table 1.

5.2. Results of different HDR Images

The results of different HDR images which are used for experiment are shown in figures below. We have applied all the steps of our method on this HDR images which we have shown earlier. The final tone mapped images of our method are compared with results of two tone mapping techniques of Drago and Durand. We have also compared the result on the basis of comparison metrics.

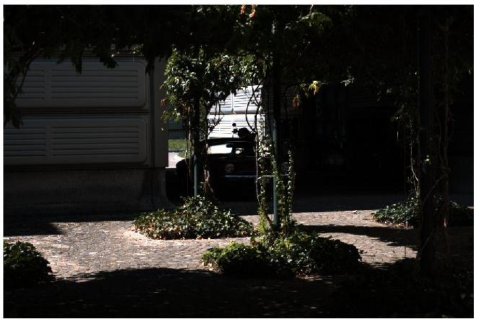
- Result of vinesunset.hdr is shown in figure 5.5

(a) Original vinesunset.hdr **(b) Durand TMO**

(c) Drago TMO **(d) our proposed method**

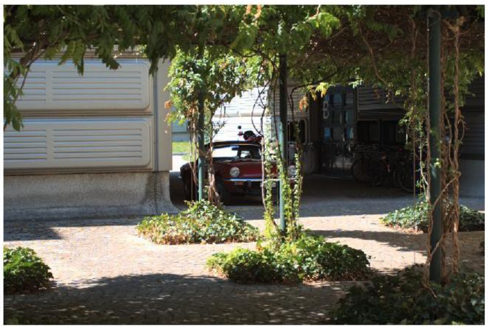
Figure 5.5: Result of experiment on vinesunset.hdr

➢ Result of auto.hdr image is shown in figure 5.6

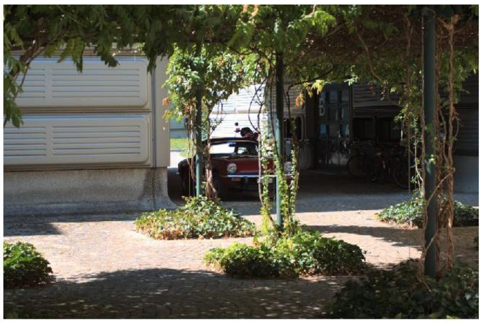


(a) Original auto.hdr

(b) Durand TMO



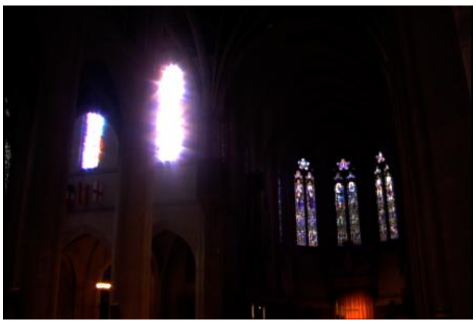
(c) Drago TMO



(d) Our Proposed Method

Figure 5.6: Result of Experiment on auto.hdr

➢ Result of nave.hdr is shown in figure 5.7



(a) Original nave.hdr

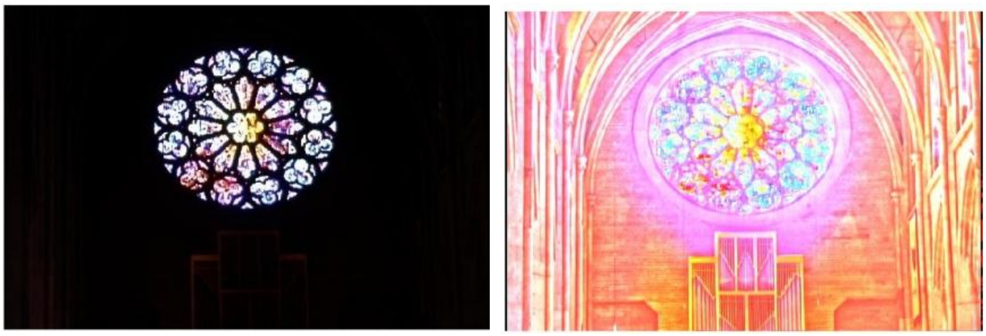
(b) Durand TMO

(c) Drago TMO

(d) Our Proposed Method

Figure 5.7: Result of Experiment on nave.hdr

➢ Result of resette.hdr is shown in figure 5.8



(a) Original rosette.hdr **(b) Durand TMO**

(c) Drago TMO **(d) Our Proposed Method**

Figure 5.8: Result of Experiment on rosette.hdr

➢ Result of groveC.hdr is shown in figure 5.9

a) groveC.hdr **(b) Durand TMO**

(c) Drago TMO **(d) Our Proposed Method**

Figure 5.9: Result of Experiment on nave.hdr

As from the results shown above it is clearly visible that the quality of tone mapped images produced by our proposed method is superior to the previous techniques. The details and contrast is preserved in tone mapped image. We have compared our results with the other two methods on the basis of comparison metrics. In our method of tone mapping, the comparison metrics have improved which are shown in table 1. When we apply the gamma correction, the quality of the tone mapped image has improved and also the comparison metrics have been improved.

- Snapshot of proposed method

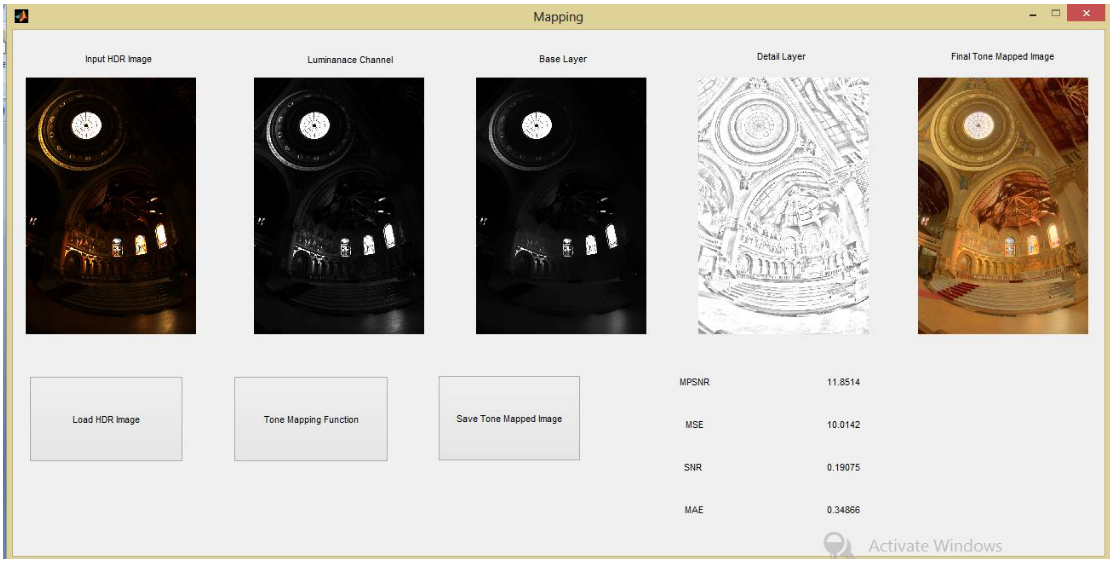


Figure 5.10: Snapshot of proposed Method

Table 1: Results of our method and the method of Durand and Drago TMO.

S. No.	Image Name	Matrices	Durand TMO	Drago TMO	Proposed TMO
1	**Memorial.hdr**	PSNR	9.991	11.642	12.361
		MSE	10.1273	10.0333	10.0216
		SNR	0.1419	0.1824	0.409
		MAE	0.3866	0.3421	0.3337
2	**Bathroom.hdr**	PSNR	12.748	13.223	13.619
		MSE	7.1235	7.1187	7.1175
		SNR	0.0088	0.0123	0.0124
		MAE	11.3036	11.2889	11.3002
3	**Auto.hdr**	PSNR	12.014	10.406	10.708
		MSE	0.0161	0.0559	0.0623
		SNR	4.9724	-0.4288	-0.8982
		MAE	0.1132	0.2076	0.2199
4	**GroveC.hdr**	PSNR	13.581	14.974	15.811
		MSE	303.018	303.0587	302.0291
		SNR	0.0582	0.0446	0.0593
		MAE	2.7159	2.7273	2.6232
5	**GroveD.hdr**	PSNR	13.278	13.419	13.913
		MSE	24.9831	25.0867	24.7301
		SNR	0.409	0.3818	0.429
		MAE	1.6236	1.6278	1.6109
6	**Nave.hdr**	PSNR	11.2315	11.1716	11.9241
		MSE	660.236	660.046	660.188
		SNR	0.0182	0.0196	0.0187
		MAE	1.4186	1.4295	1.4077
7	**Rosette.hdr**	PSNR	8.1839	8.542	8.675
		MSE	2.7867	2.7717	2.7576
		SNR	0.8459	0.8345	0.8566
		MAE	0.3891	0.3694	0.3609
8	**Doll_doll.hdr**	PSNR	3.5186	4.3546	4.9414
		MSE	0.0566	0.0835	0.0142
		SNR	-10.791	-12.4823	-9.629
		MAE	0.2128	0.2129	0.1528

Chapter 6
Conclusion and Future Scope

6.1 Conclusion

In this thesis a new tone mapping algorithm is implemented by using the MATLAB which reduces the dynamic range and also preserves the details. First the luminance channel of the input HDR image has been extracted. Then we used the bilateral filter for the decomposition of the image into two layers i.e. base and detail layer. After that the luminance values of base layer has been compressed by using the logarithmic mean and a bias power function. Then the contrast reduced base layer and detail layer have been merged and a tone reduced image is obtained. And finally gamma correction is applied to improve the contrast in the dark areas. The quality of the tone mapped images is also good as compared to other tone mapping algorithms. The comparison is done on the basis of 4 comparison metrics, which shows that the proposed methodology is superior to the previous techniques.

6.2 Future Scope

There are many different methods of tone reduction of High Dynamic Range images are available. But the quality of the tone mapped images is not quite good. So new methods of tone mapping can be implemented which can improve the quality of the images. In future, we can work on obtaining the base layer by using a more precise function which can easily decompose the image and also intend to do experiments so that it can be easy to determine the automatic bias value as a function according to the scene and its dynamic range of luminance. Also the halo artifacts which are generally introduced in local tone mapping techniques can be avoided by using both the global and local tone mapping in combination.

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List of Publications

1. Himanshu Kasliwal and Shatrughan Modi, "A Novel Approach for Reduction of Dynamic Range Based on Hybrid Tone Mapping Operator," accepted at *Second International Symposium on Computer Vision and the Internet (VisionNet'15)*, SCMS, Kochi, 2015 will be published in "*Procedia Computer Science"*.

Video Presentation

1. https://www.youtube.com/watch?v=t-71E2Fgq_4.