A New Technique to Reproduced High-Dynamic-Range Images for Low-Dynamic-Range Display

Tung Li Qian[#1], Suhaidi Shafie[#2], M.Iqbal Saripan[#3]

[#1,2]Deparment of Electrical and Electronic Engineering,

[#3]Deparment of Computer and Communication System Engineering,
Universiti Putra Malaysia
43400 Serdang , Malaysia

[1]lqtung@yahoo.com

[2]suhaidi@ eng.upm.edu.my

[3]iqbal@ eng.upm.edu.my

***Abstract*—Tone mapping is a process for reproduction of High-Dynamic-Range images (HDR) for Low-Dynamic-Range (LDR) output devices. In this report, author presents a new local tone-mapping operator, derived from the Contrast Limited Adaptive histogram Equalization (CLAHE) technique for displaying high dynamic range image. The CLAHE is a method which was originally developed for medical imaging. This method has effectively expanded the full dynamic range of display and it is fully automatic. Due to different luminance intervals could result in overlapped reaction on the limited response in limited response range of visual system, scene region splitting and merging were used to segment the scaled luminance and perform the image segmentation to segment image into smaller part. After the region splitting and merging, there will be some noise or variation of intensity that may result in holes or over segmentation. As the result, the morphological operation, opening and closing were used to perform the mask to applied different clip limit of the CLAHE operation.**

***Keywords*— tonemapping, high-dynamic-range, image,CLAHE, luminance**

I. INTRODUCTION

The environment is full of wide range of luminance levels. Humans' eyes do not have problem in viewing such a wide range. Humans' visual systems even have the ability to instantaneously and seamlessly adapt to scenes with a large dynamic range, scenes that can exceed 10000 to 1 between sunlight and shadows [1]. However, the photographic process faces the limit by the photosensitive material.

Although there are some cameras that are able to capture large dynamic range of light intensity but it is very expensive. Commercial cameras can only capture limited dynamic range of light intensity. When capturing a scene which contains a dynamic range above the limitation of the camera, loss of detail will occur in the lowlight areas, the highlight areas, or both [2]. In order to overcome to limitation, HDR imaging brings a totally new visual experience to recording and displaying real-world equivalent images and video. This technique can capture the complete light information about the scenes. The HDR image can be obtained with widely available camera typically 12-16 bit resolutions or by combining different exposed images to the same scene in 32-bit floating-point number format [3].

However, for most of conventional display device such as plasma, CRT, LCD and printers in the market cannot reproduce the exactly HDR image due to they have a Low-Dynamic-Range (LDR) from 1000:1 cd/m^2 [4].

Therefore, in order to view HDR image on conventional display devices, the range of the value should be transformed to a displayable range by a process called tone mapping or tone reproduction. Tone mapping can be defined as the conversion from real world to display luminance. Tone mapping is a technique for the purpose of reducing contrast and brightness in HDR images to enable their depiction on LDR devices. The process of tone mapping is performed by a tone mapping operator.

The tone mapping operator is used to try to preserve aspects of an image such as contrast, brightness or fine detail— aspects that might be lost through compression [5]. There are two type of tone mapping operators: global (spatially uniform) and local (spatially varying) [6]. For global operator, each pixel applies the same transformation for example, logarithmic function, gamma function, and sigmoid function. These global algorithms tend to preserve the subjective perception of the scene and have advantage of being simple and fast. However, global algorithm will cost lost of the detail information of the image. Local tone mapping operator applies a different scale to different parts of an image. These methods makes the local operator-based methods give more details of the image than those global operator based methods. However, they may also cause "halo" effects or ringing artefacts in the reproduction. [7]

The author of [8] introduces a global tone mapping operator which base on a new histogram adjustment technique, based on the population of local adaption luminance in a scene. The method of histogram adjust was well known as simple, fully automatic. It does not depend on image-dependent or user-defined parameters.

In this report, we propose a tone mapping to display high-dynamic-range image. We first use the modified the CLAHE method which was originally developed for medical imaging. This method has effectively expanded the full dynamic range of display. Then we extend the CLAHE method to a new local tone mapping operator. The new local tone mapping operator segments the image into smaller part and perform the CLAHE base on the method.

II. Proposed Method

In this section, a new tone mapping algorithm is presented. Our work is process only the luminance channel. As the result, we first introduce how to calculate the luminance values. Then a brief description of the CLAHE technique is shown and lastly the local adaption idea was present.

A. Global tone mapping operator

An HDR image input is typically a floating point RGB image, which is linear to the absolute luminance. In the LHS (luminance, hue and saturation) system, the luminance is defined as

$$L(x, y) = 0.299R(x, y) + 0.587G(x, y) + 0.114B(x, y) \text{---(1)}$$

By using the log-average reproduction function, the log average luminance value (Y_{av}) is calculated as

$$\mathrm{Y_{av}} = \frac{1}{\mathrm{N}}\sum_{\mathrm{x,y}} \log_2(\sigma + \mathrm{Y(x, y)}) \text{-----(2)}$$

Where N is the number of pixel in the image and Y(x, y) is the input luminance. The σ is a small value to avoid the singularity that occurs if the black pixels which is equal to 0 are present in the image.

In this stage, the log average reproduction luminance value for display in the display device will losses a lot of information and contrast. This is because this step did not count on the image's pixel distribution characteristic. In this step, a lot of pixels was squeezed into the same category of display level while only a few of pixel occupy the important display level. There is a traditional technique that takes into account on pixel distribution is histogram equalization. Histogram equalization technique is traditionally used for low-dynamic-range image enhancement. Author of [8] used it for mapping the luminance in high-dynamic-range scene to the available display level. However usually histogram equalization comes with extreme contrast enhancement of highly populated bins and intensive compression of sparsely populated bins which will make the image become too noisy.

In order to overcome the problem of histogram equalization, a method which is the extension of histogram equalization has been introduced called Contrast Limited Adaptive Histogram Equalization (CLAHE). The CLAHE algorithm was originally developed for medical imaging and proven to be successful for enhancement of low contrast images.

The CLAHE method differs with the traditional histogram equalization with the CLAHE method divides the input image in a grid of rectangular contextual regions. Besides, to avoid over enhancement on the image, a clip limit was introduced to prevent this problem. The clip limit was use to limit the slope of associated cumulative distribution, which means that the density probability function cannot exceed a certain value.

The input of the original CLAHE algorithm is a grayscale image with initially spilt into rectangular regions. Each region of the histogram is then computed with a certain number of bin, B. Therefore, the generic region (k, l) has the histogram function $H_{k,l}(s)$, with

$$s \in [0, B-1] \text{----(3)}$$

The clip limit, β was then using to threshold the pixels that excess in each bin. If the pixel is one of the bin is excess β, the pixels will redistributed until they do not exceed. The clip limit can be calculated by using following formula.

$$\beta = \frac{N}{B.\alpha} \text{----(4)}$$

Where N represent the total of the pixel and $\alpha \in [0, 1]$ represents the maximum percentage of pixels allowed in a given bin. The obtained histogram is then normalized and used to estimate the cumulative probability function $g_{k,l}(x)$ which is the mapping function estimated for the region of index k, l. Then the interpolation stage is done to avoid boundary effect. At the end, each pixel has its own mapping function, which can be globally expressed as:

$$T(i, j, s) = (B-1).\sum_{i=0}^{s} F_{i,j\,(s)} \text{---- (5)}$$
$$\text{With } s \in [0.\ B-1]$$

Where (5) represent the distribution function after apply interpolation.

B. Local Tone Mapping Operator

Stevens and Steven [11] carried out experiments to scientifically explain human visual response versus different luminance levels under different adaption levels. In their experiment, an observer was first adapted to a background with uniform luminance, i.e. an adaption level. Then they were gradually presented a small target luminance which was different with adaptation luminance level. The experiment result showed that different luminance intervals could result in overlapped reaction on the limited response in limited response range of visual system, thus extending our visual response range to cope with the full dynamic range of high contrast scenes. [12]

By referring to the experiment above, we design a new local tone mapping operator to better render high-dynamic-range image for display.

The CLAHE works effectively after effective utilization the log average reproduction luminance to the dynamic range of the display device. However, if we can segment their image into smaller regions and apply the CLAHE in each local area with different clip limit, each area would have a fully display dynamic range to utilize based on its local pixel statistics. This is equivalent with the experiment result of [11].

In our local tone mapping operator, the first step is the log-average reproduction function. The following step is to determine to which local regions we will apply the CLAHE with different clip limit. There are a lot of methods to segment the image into local area such as clustering and the method used in [5]. In this report, we proposed a efficiency local operator, which use region splitting and merging to segment the log average reproduction luminance, Lav. In order to segment the entire image into the region, region growing technique is used. Region growing is a simple region-based image segmentation method. It is also classified as a pixel-based image segmentation method since it involves the selection of initial seed points. This approach to segmentation examines neighbouring pixels of initial "seed points" and determines whether the pixel neighbours should be added to the region. Let *R* represent the entire image region and select a predicate *P*. The "seed points" in this case is the standard deviation, σ. This approach for segmenting *R* is to subdivide it successively into smaller and smaller quadrant regions so that, for any region, R_i, that standard deviation, $\sigma \leq 5$, $P(R_i)$ = TRUE. If $P(R)$ = FALSE, we divide the image into quadrants. The particular splitting technique has a convenient representation in the form of a so-called quadtree. If only splitting were used, the final partition likely would contain adjacent regions with identical properties. This drawback may be remedied by allowing merging, as well as splitting. Merge only adjacent regions whose combined pixels satisfy the predicate *P* which is $\sigma \leq 5$. The two adjacent region R_j and R_k are merged only if $P(R_j \cup R_k)$ = TRUE.

After the region splitting and merging, there will be some noise or variation of intensity that may result in holes or over segmentation. As the result, morphological operation (opening and closing) was used to process the mask. Opening generally smoothes the contour of an object, breaks narrow isthmuses, and eliminates thin protrusions. For our case, opening was used to remove the smaller objects in an image after the splitting and merging process. Closing also tends to smooth sections of contours but, as opposed to opening, it generally fuses narrow breaks and long thin gulfs, eliminates small holes, and fills gaps in contour. As the result, closing was used to join the circles in the image together by filling in the gaps between them and by smoothing their outer edges. Figure 3 shows the segmentation result.

Since the CLAHE is tile processing, tile size need to be decided. The tile size is defined to be [16 16] in this report. Then, the image is checked if it needs to be padded. Padding occurs if any dimension of a single tile is an odd number or image dimensions are not divisible by the selected number of blocks, given that tile processing need to have regular shape. As a result, the image and mask should be padded to split the image and the mask to regular blocks. In every small block, it may include more than one mask flag, the minority mask flag were then change to the majority mask flag in the block.

Based on the pixel statistic in each area, we compute the local CLAHE. In each area, we assign different clip limit according to the tile's mean and variance. This step alleviates the artifacts introduced by the original CLAHE algorithm. First, the average mean and variance value of the region made by blocks with the same mask flag mark were used to calculate the clip-limit and the blocks with same mark have the same clip-limit. The step continues to calculate every block with different mask flag using following formula

$$\alpha(area) = \begin{cases} \min\left(\frac{area\_var}{area\_mean} \times 0.005 + 0.005, 0.01\right) & \text{area\_mean} > 127 \\ \min\left(\frac{area\_var}{area\_mean} \times 0.005 + 0.01, 0.015\right) & others \end{cases} \text{--------(6)}$$

$$\alpha(block) = \begin{cases} \min\left(\frac{blk\_var}{blk\_mean} \times 0.005 + 0.005, 0.01\right) & \text{blk\_mean} > 127 \\ \min\left(\frac{blk\_var}{blk\_mean} \times 0.005 + 0.01, 0.015\right) & others \end{cases} \text{----------(7)}$$

$\alpha(area)$ decides the area information (the area with the same mark in the mask). The $area\_var$ is the variance value of the area, and the $area\_mean$ is the mean value of the area. $\alpha(block)$ decides only by the block's information, the blk_var is the block's variance value, and the blk_mean is the block's mean value. If the mean is larger, the block is brighter. Larger variance means the block is with richer content. If the $(blk\_var)/(blk\_mean)$ is larger, the block is more complex. As a result, the contrast should be stronger. If the mean of the block is larger than 127, it is considered a bright area, and the $\alpha(area)$ and $\alpha(bloack)$ need to be between 0.005 and 0.001 since this range had been experimentally determined to achieve best result for bright areas with high variance. For dark areas, the $\alpha(area)$ and $\alpha(bloack)$is between 0.01 and 0.015 since the contrast of a dark area with low variance must not be over stretched.

The α is then decided by $\alpha(area)$ and $\alpha(block)$ both as follow:

$$\alpha = \left(\alpha(block) + \alpha(area)\right)\text{------(8)}$$

$$\beta = \left(x + [(y - x)/2] \times \alpha\right)\text{------(9)}$$

$$x = y/256 \quad \text{------(10)}$$

The β is the clip limit where x is minimum clip limit and y is the number of pixels in a block. After the clip limit is discovered, the mapping is done. This is similar to the traditional CLAHE but each clip-limit of the block is different. Lastly, interpolates between neighbouring tile mapping were performed to remove artificially induced block borders. Otherwise, these borders would become quite visible

C. *Tonemapping*

After the local tone mapping, following formula is used to compute the output LDR pixels

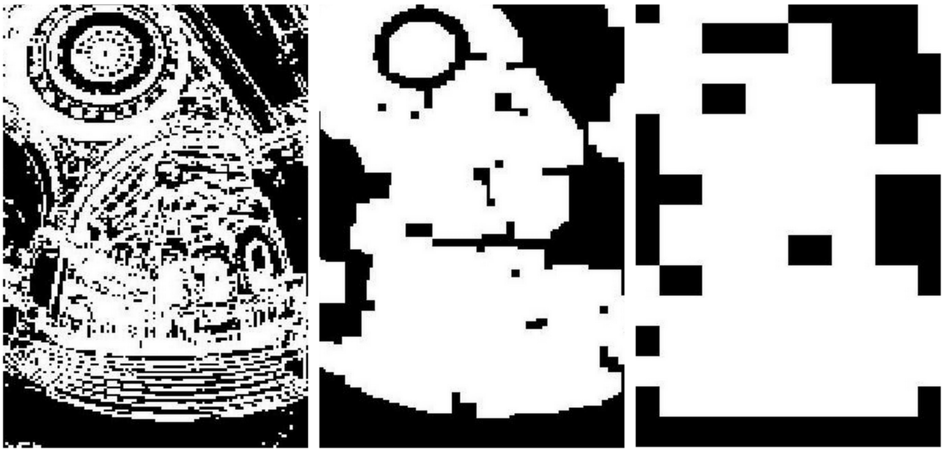
$$R_{out} = \left(\frac{R_{in}}{L_{in}}\right)^{\gamma} L_{out}, G_{out} = \left(\frac{G_{in}}{L_{in}}\right)^{\gamma} L_{out}, B_{out} = \left(\frac{B_{in}}{L_{in}}\right)^{\gamma} L_{out} \text{------(11)}$$

where L_{in} and L_{out} are luminance values before and after tone reproduction. The γ controls the saturation of the

III. RESULT AND DISCUSSION

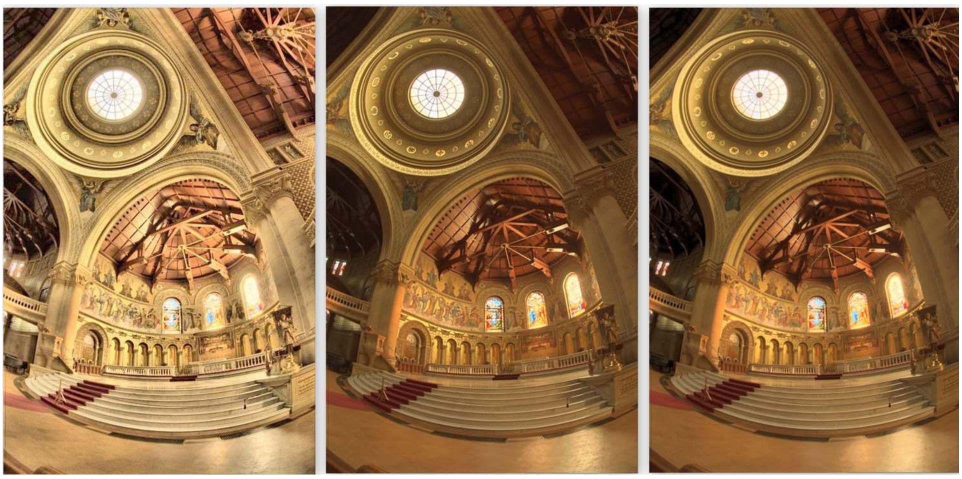
In our simulation, we compute the HDR luminance image by using equation (1) first which is shown in Fig. 1(a). Then the HDR luminance is the mapped into the display luminance by log average reproduction function (2) which was shown in Fig. 1(b). Third, the image segmentation using region splitting and merging was shown in Fig. 2(a). Then the mask after opening and closing method was shown in Fig. 2(b) and lastly the regular mask after converting to regular block was shown in Fig. 2(c).. However, until now, there are not any standard of objective evaluation available to measuring the quality of displayed HDR images because it is difficult to know how the light or dark the image should be displayed to faithful to the original HDR image [16]. As the result the main evaluation is based on human's subjective evaluation. In this report, we consider this to evaluate the performances with different tone mapping method. In Fig.3, we compare our algorithm with other tone mapping method. Fig 3(a) shows an image processed with our algorithm. When compare to Reinhard's method [9] and Ward's method [8] as shown in Figure 3(b) and (c), our algorithm can preserve more visual detail in both the dim and bright area under a good overall impression

Fig. 1.(a) HDR Luminance (b)Mapped Luminance



(a) **(b)** **(c)**

Fig. 2.(a) image obtained after region splitting and merging. (b) mask obtained after the opening and closing method. (c) regular mask.



(a) **(b)** **(c)**

Fig. 3. Comparison of HDR image on different tone mapping operator. (a) proposed operator. (b) Reinhard's operator [9]. (c) Ward's operator [8].

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