High Dynamic Range Image Tone Mapping with Edge Preserved Dithering

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ABSTRACT
Current tone mapping technique for high dynamic range (HDR) image is limited by the gray scale of display screen. In this paper, we propose a novel tone mapping approach based on edge preserved dithering, which makes use of high resolution of display screen to break through the gray scale limitation. To each HDR image, we first decompose its L* component to the ditherable patches and the unditherable patches. Then, we utilize linear programming to tone map the mean gray levels of the ditherable patches and the gray level of each pixel in the unditherable patches to an extended dynamic range. Finally, the gray levels of the tone mapped image are further narrowed to the required gray scale of display screen in which dithering is applied on ditherable patches. Experimental results show that edge preserved dithering can improve the distribution of the limited gray levels in the generated images and effectively reduce contouring and detail loss.

Categories and Subject Descriptors
1.4.9 [Image Processing and Computer Vision]: Applications

General Terms
Algorithms, Human Factors

Keywords
High dynamic range image, tone mapping, edge preserved dithering, high contrast

1. INTRODUCTION
Compared to conventional digital image technology in low dynamic range (LDR), high dynamic range (HDR) imaging captures illumination in a higher range, which provides more detail information and better view experience [1]. Especially on mobile phones, HDR imaging has been a default function for their cameras, in which HDR image can be conveniently generated by capturing several LDR images with same content and different exposures [6, 10].

Similar to other devices, mobile phone is limited by its screen gray scale in HDR image display. The recorded illumination information in HDR images has a much greater dynamic range than the display ability of current LCD or LED screens. As shown in Figure 1(a), linear mapping HDR image to adapt to the gray scale of display screens will cause serious information loss. So it requires non-linear tone mapping methods for HDR image to adapt to the gray scale limitation of display screens, which can preserve more details in the generated LDR image.

In the past decades, a variety of tone mapping methods have been proposed for HDR image display. Pisano et al. transferred the dynamic range of HDR image by contrast-limited adaptive histogram equalization [9]. Durand et al. decomposed the image into a base layer and a detail layer with bilateral filter, and only reduced the contrast in the base layer to preserve details [4]. Mantiuk et al. considered ambient illumination and display characteristics, and minimized visible contrast distortion using higher order image statistics and quadratic programming [7]. Duan et al. segmented HDR images into regions and carried out adaptive contrast adjustment on the local regions to reproduce local contrast [3]. Gu et al. proposed an edge-preserving filter for multiscale decomposition of HDR image, and reduced the detail layer [5].

Current tone mapping methods mainly focus on improving the distribution strategy of the limited gray levels of display screens for the pixels in HDR image. Each gray level in the whole HDR image or a region is mapped to a gray level in the generated LDR image, and all the pixels in HDR image are handled separately. Obviously, the performance of these methods is influenced by the gray scale of display screen. Insufficient gray scale of display screen may cause serious detail loss or obvious artifacts. Hence, increasing the gray scale of display screen will benefit to display HDR images.

In this paper, we propose a novel tone mapping approach, which utilizes edge preserved dithering to break through the gray scale limitation of display screens. Our approach is inspired of a fact, that the screen resolutions of many mobile phones have exceeded the distinguishing ability of human eyes. Making use of the high screen resolution of mobile phone, we treat each patch in HDR image as a unit in tone mapping, and apply dithering on the selected patches to...
Figure 1: Overview of the proposed approach. (a) HDR image. (b) Preprocessing result on \( L^* \) component of HDR image. (c) Tone mapping. (d) Tone mapped \( L^* \) component. (e) Generated LDR image.

Figure 2: Example of dithering. (a) Dithering patterns. (b) and (c) No dithering and pattern dithering based on the same basic gray levels. (d) Influence of high resolution of mobile phone screen.

provide higher dynamic range in representation than the real gray scale of display screen (Figure 1(e)).

Figure 1 shows an overview of the proposed approach. To each HDR image (Figure 1(a)), its \( L^* \) component in CIELAB color space is first decomposed into patches. The patches without obvious edges are selected as “ditherable patches” (red patches in Figure 1(b)) and other patches are treated as “unditherable”. Then, the gray levels of the pixels in unditherable patches and the mean gray levels of ditherable patches are tone mapped to an extended dynamic range by linear programming based high contrast tone mapping (Figure 1(c)). After that, the gray level of each pixel is further narrowed to the given gray scale of display screen, in which dithering is applied on the ditherable patches to represent various gray levels (Figure 1(d)). Finally, the LDR image is generated by combining the tone mapped \( L^* \) component and other two components from HDR image (Figure 1(e)). By extending the dynamic range by edge preserved dithering, our approach can distribute more gray levels to represent the details and avoid contouring in smooth regions with a limited number of gray levels in the generated LDR images.

2. DITHERING

Dithering can approximate the unavailable gray levels by combining a limited number of gray levels [11]. As shown in Figure 2(a), two basic gray levels are given in the left and right, and three extended gray levels are approximated by the patches composed of the pixels in the two basic gray levels with different patterns. When watching the patches, human eye perceives them as a mixture of the basic gray levels within them. Obviously, dithering is helpful to provide various gray levels and avoid some artifacts caused by quantization, such as contouring. But it brings the patterns in image representation, which are only not indiscernible when viewing the images from a distance.

When view a image on mobile phone, the distance between human eye and mobile phone screen satisfies the requirement. As shown in Figure 2(d), the distance between human eyes and mobile phone is about 400mm in daily use, and the minimum view angle of normal vision is \( 1' \). So the minimum distance can be distinguished on mobile phone screen is about 0.12mm, which covers more than one pixels on the screens of many mobile phones.

There have been some tone mapping methods using dithering, such as [2] and [8]. These methods only directly use dithering to represent the additional one or two bits in each gray level representation. Different to them, our approach applies dithering in tone mapping for HDR image, which can improve the distribution of gray levels in LDR image and avoid detail loss and contouring.

3. TONE MAPPING WITH EDGE PRESERVED DITHERING

3.1 Preprocessing

For \( L^* \) component of each HDR image, we decompose it into patches with the size of \( 2 \times 2 \), on which dithering can represent three extended gray levels between two adjacent gray levels (Figure 2(a)).

To avoid edge blurring caused by dithering, we calculate the horizontal and vertical gradients for each pixel, and sum the gradients within each patch. Then, we define a threshold \( \delta_{gra} \) to identify whether a patch is suitable for dithering, which equals 0.01 in our experiments. If the sum of gradients within a patch is smaller than \( \delta_{gra} \), we treat the patch as a ditherable patch and apply dithering on it; otherwise, we treat the patch as a unditherable patch and deal with the pixels within the patch separately in tone mapping.

3.2 High contrast tone mapping

The proposed edge preserved dithering strategy is independent to the basic tone mapping, i.e., it can be applied in different tone mapping methods. Here, we select OCTM method [12] as the basic tone mapping method, and improve it for high dynamic image tone mapping.

Assume the HDR image \( I_{hdr} \) is with the gray scale of \( L_{hdr} \), and the generated LDR image \( I_{ldr} \) is limited with the gray scale of \( L_{ldr} \). Let gray level \( l_{hdr}^k \) in \( I_{hdr} \) tone map to the gray level \( l_{ldr}^k \) in \( I_{ldr} \), and define the increment of each gray
level \( l^k_{dr} \) as \( s^k = t^k_{dr} - t^{k-1}_{dr} \), here \( l^0_{dr} = 0 \). OCTM method enhances image contrast by linear programming as follows:

\[
s^* = \arg \max s \sum_{k=1}^{L_{hdr}} \rho^k s^k \\
\text{s.t.} \quad (a) \quad \sum_{k=1}^{L_{hdr}} s^k = L_{ldr} - 1 \\
\quad (b) \quad s^k \geq \frac{1}{d}
\]

where \( s = \{s^1, s^2, \ldots, s^{L_{hdr}}\} \) is the increment vector, \( \rho^k \) equals the appearance probability of pixels in \( I_{hdr} \) whose gray level is \( k \); and \( d \) is a parameter to avoid binary tone mapping, which equals 2 or 3.

For dithering can extend the number of gray levels, for example, dithering on \( 2 \times 2 \) patch can provide three extended gray levels between two adjacent gray levels. So we modify constraint (a) in Eq. (1) by using the extend gray scale instead of \( L_{ldr} \):

\[
\sum_{k=1}^{L_{hdr}} s^k = L_{ext} - 1
\]

where \( L_{ext} \) equals \( 4(L_{ldr} - 1) + 1 \) according to Figure 2(a).

For \( L_{hdr} \) is much higher than \( L_{ldr} \) in tone mapping of HDR image, constraint (b) in Eq. (1) may cause contradiction to constraint (a) even the number of gray levels is extended as Eq. (2). So we modify the lower bound of \( s^k \) to \( L_{ext}/dL_{hdr} \). To avoid distributing too many gray levels in LDR image to some gray levels with the high probabilities in HDR image, we set the upper bound of \( s^k \) as 1. Constraint (b) in Eq. (1) is modified as follows:

\[
\frac{L_{ext}}{d \cdot L_{hdr}} \leq s^k \leq 1.
\]

Based on the constraints in Eq. (2)-(3), we solve the optimal increment vector \( s^* \), and further calculate the tone mapped gray level \( l^k_{ext} \) of the gray level \( l^k_{hdr} \) as follows:

\[
l^k_{ext} = \lceil \sum_{i=1}^{k} s^i + 0.5 \rceil.
\]

### 3.3 Edge preserved dithering

Each gray level \( l^k_{dr} \) in HDR image has been mapped to the extended dynamic range \( [0, L_{ext} - 1] \), which should be further narrowed to \( [0, L_{ldr} - 1] \).

To each ditherable patch, we apply dithering on it based on its primary gray layout. Assume the mean gray level of the patch is tone mapped to \( l^k_{ext} \) in the extended dynamic range. We calculate the base gray level of the patch in LDR image as follows:

\[
l^k_{ldr} = \left\lfloor \frac{l^k_{ext}}{4} \right\rfloor.
\]

Then, we determine the type of dithering pattern applied on the patch as follows:

\[
\tau^k = \text{mod} (l^k_{ext}, 4).
\]

If \( \tau^k = 0 \), it means that no dithering pattern should be used and the gray levels of all the pixels within the patch are set to \( l^k_{ldr} \). If \( \tau^k > 0 \), we select \( \tau^k \) pixels in the patch and adjust their gray levels to \( l^k_{ldr} + 1 \). The selection of the pixels to adjust their gray levels is random in conventional dithering. To preserve the gray layout in the patch, we select the \( \tau^k \) pixels with highest gray levels in HDR image and adjust them gray levels in LDR image.

To each unditherable patch, we transfer the gray level of each pixel within it by Eq. (5). In this way, gray level of each pixel is narrowed the required dynamic range.

### 4. EXPERIMENTS

#### 4.1 Dataset and experiment setting

We validated the proposed approach on two public HDR image datasets, Funt et al HDR Dataset and HDRSID Dataset. To avoid the bias in assessment, we removed the near duplicate images within each dataset, and retained 107 images and 232 images in these two datasets, respectively.

For the gray level of HDR images in the datasets is represented by real number, we quantified it to discrete gray level based on gray distribution of each image. In our experiments, \( L_{hdr} \) was assigned to \( 2^{16} \), and \( L_{ldr} \) was assigned to 256. All the experiments were implemented in Matlab on a computer with 3.4GHz CPU and 8GB memory.

#### 4.2 Experiment results and discussion

To illustrate the improvement of using edge preserved dithering, we compared our approach with the original OCTM method. Figure 3 shows some examples of results comparison, in which we use the results of linear mapping and contrast-limited adaptive histogram equalization method (CLAHE) [9] to represent the dynamic range and content of HDR images. It is obvious that CLAHE method is easy to cause washed-out effect in the generated LDR images, and OCTM method and our approach can avoid it well (Figure 3(b)-(d)). Compared to OCTM method, our approach provides various gray layout in representation, e.g., the sky in the second column, and avoid contouring, e.g., the ground in the third column. It can also retain more details by improving gray level distribution and acquiring more gray levels for detail representation, e.g., the traces on the ground in the fourth column. The fifth and sixth columns in Figure 3 show that our approach can generate good tone mapping results of the HDR images with complex details.

To quantitatively evaluate the effectiveness of edge preserved dithering in tone mapping, we carry out a user study. Fifteen participants in age of 23 to 35 were invited, including nine males and six females with occupation of graduate and officer. During the evaluation, each pair of LDR images generated by OCTM method and our approach from the same HDR image was required to be compared by three participants, and the dominant judgment was treated as the final evaluation. Table 1 shows the result of user study, in which “Better”, “Similar” and “Worse” denote the number of our results are better, similar and worse than/to the corresponding results of OCTM method, respectively. We can find that edge preserved dithering effectively improves the quality of the generated LDR images.

In experiment, we also found some drawbacks of our approach. For example, it may cause artifacts when HDR image is overcast with textures, e.g., the first row in Figure 4. In addition, similar to OCTM method, our approach may over-enhance textures in maximizing image contrast, e.g., the second row in Figure 4.

### 5. CONCLUSIONS

In this paper, we propose a tone mapping approach for HDR image using edge preserved dithering. Based
Figure 3: Example of comparison results. (a) Linear mapping. (b) CLAHE. (c) OCTM. (d) Our results.

Table 1: Result of user study.

<table>
<thead>
<tr>
<th>Funt et al HDR Dataset</th>
<th>HDRSID Dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better</td>
<td>58</td>
</tr>
<tr>
<td>Similar</td>
<td>36</td>
</tr>
<tr>
<td>Worse</td>
<td>13</td>
</tr>
</tbody>
</table>

Figure 4: Example of failure results. (a) Linear mapping. (b) CLAHE. (c) Our results.

on the identified ditherable patches in HDR images, edge preserved dithering improves the gray level distribution of the generated LDR image during tone mapping, which is helpful to provide better view experience by avoiding contouring and retaining more details.

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7. REFERENCES


