# An Improved Tone Mapping Algorithm for High Dynamic Range Images

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***Abstract*—Real world scenes contain a large range of light intensities. To adapt to display device, High Dynamic Range (HDR) image should be converted into Low Dynamic Range (LDR) image. A common task of tone mapping algorithms is to reproduce high dynamic range images on low dynamic range display devices. In this paper, a new tone mapping algorithm is proposed for high dynamic range images. Based on the probabilistic model is proposed for high dynamic image's tone reproduction, the proposed method uses a logarithmic normal distribution instead of normal distribution. Therefore, the algorithm can preserve visibility and contrast impression of high dynamic range scenes in the common display devices. Experimental results show the superior performance of the app roach in terms of visual quality.**

***Keywords- tone mapping; high dynamic range image; low dynamic image; energy minimization***

## I. INTRODUCTION

Recent years, new technologies have made it easier to create HDR images. They can generate the full dynamic range by a sequence of LDR images of the same scene, which can be captured by the general camera under different exposure time [1].The dynamic range of natural world luminance can reach $10^8:1$, but that of displayed luminance is about 100~1000:1 for most screen devices such as CRTs or LCDs. Although HDR monitors will be more widely available in the near future, they are still rare and costly and, at the same time, difficult to calibrate [2].

The discrepancy makes the accurate display of real world scenes difficult. As the advances of HDR capture technologies, HDR images or videos are available. Image processing schemes such as tone mapping resolve the issue of rendering HDR images on LDR displays while preserving the visual contents [2]. The HDR image is able to exhibit the details of extremely dim and extremely bright regions, which may be lost in common LDR images while tone reproduction is processed but can be perceived by the human visual system (HVS).

Tone mapping is commonly classified into the "global" and "local" tone reproduction [3]. The global tone reproduction adopts the same mapping scheme for all the pixels in the image. This makes it computationally efficient. Miller, etal., proposed a global tone mapping scheme using nonlinear operators [8]. Tumblin and Rushmeier introduced the tone reproduction based on the human visual system [9]. Another is content-based, which use local gradient information to enhance its contrast while the former method is a global one. But the latter method will spend more time and computing resource.

SONG Ming-Li and his colleagues proposed a tone mapping for HDR Image using a probabilistic model [11]. This novel method learns a distribution for local pixel energy of the tone. With the constraint of the gradient variation on the HDR image, an energy distribution is set up based on the similarity between the gradient variation on the HDR and the LDR image. The probabilistic framework for the tone mapping operation is formulated into an energy minimization process by a Maximum A posteriori (MAP) deduction.

In this paper we start from the model. Under a special function rule, we will get a mixed method to get the better performance for the HDRI to display it in the common monitor. The paper is organized as follows. In section II, we will propose the algorithm for HDR image, Section III proves its theoretical result by several HDR image. Finally we conclude the paper.

## II. THE PROPOSED TONE MAPPING ALGORITHM FOR HDR IMAGE

There are two rules for tone mapping, the bright one should also be bright after this processing (so the mapping function should be monotone); and the detail information should be preserved as much as possible.

We can convert tone mapping to a question of maximum likelihood estimation:

$$\max f\left(I_l \middle| I_h\right) \tag{1}$$

Here random variable $I_l$ is the LDR image, variable $I_h$ is the HDR image. Then we suppose that all possible LDR image's probability density function is $f(I_l)$. Probability density function that $I_l$ keeps the details of $I_h$ is $f(I_h|I_l)$.

$l_h(u,v)$ is the luminance at each point $(u,v)$ in HDR image, and $l_l(u,v)$ is the luminance at each point $(u,v)$ in LDR image. According to Bayes rule, than we have:

$$\begin{aligned}\max f(I_l|I_h) &= \max f(I_h|I_l)\, f(I_l)/f(I_h) \\ &\propto \max f(I_h|I_l) f(I_l) \\ &\propto \max \prod_{u,v} f(l_h(u,v)|l_l(u,v)) f(l_l(u,v))\end{aligned} \tag{2}$$

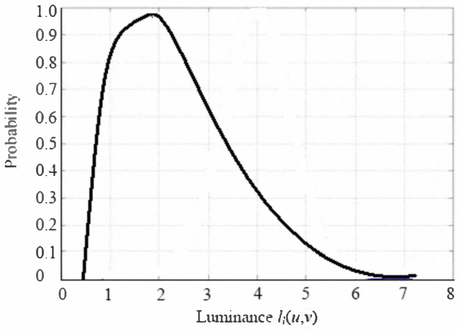



Figure 1. Energy distribution

Pixel $(u,v)$ is the basic unit of tone mapping. Energy distribution is provided in Figure 1. The transform of every pixel is calculated by logarithmic normal distribution instead of normal distribution. Then density function of the pixel's energy distribution as followed:

$$f(l_l(u,v)) \propto \frac{1}{l_l(u,v)\sigma_e(u,v)}\exp\left(-\frac{(\ln l_l(u,v)-\mu(u,v))^2}{2\sigma_e(u,v)^2}\right) \quad (3)$$

where $l(u,v)$ is the luminance of pixel $(u,v)$.

We can make sample estimate $\mu(u,v)$ through different energy of tone mapping. For the HDR image, According to the different exposure level, the LDR image sequence $c=\{1,2,\cdots,C\}$ is generated. To make the luminance of every pixel is in visible range, as the range of 0 to 255. C is the number of LDR images. $\mu(u,v)$ is the maximum luminance of $f(l_l(u,v))$, then the maximum local Energy of $(u,v)$ can be denoted by laplacian operator.

$$\nabla^2 l_l(u,v) = \frac{\partial^2 l_l(u,v)}{\partial u^2} + \frac{\partial^2 l_l(u,v)}{\partial v^2} \quad (4)$$

During the numerical computation, we can take:

$$\nabla^2 l_l(u,v) \approx |4l_l(u,v) - l_l(u-1,v) - l_l(u+1,v) - l_l(u,v-1) - l_l(u,v+1)| \quad (5)$$

So, the luminance of the pixel is the maximum energy sampling value in local pixel.

$$l_l(u,v) = \arg\max_{l_l(u,v)} \nabla^2 l_l(u,v) \quad (6)$$

The neighborhood of pixel $(u,v)$ is the base unit that determines the similarity of gradient. Then we can get the gradient distance of HDR and LDR images, and the distance can determine the similarity of the two, so the function of similarity can be denoted by followings:

$$g(u,v) = |\nabla \ln l_h(u,v) - \nabla \ln l_l(u,v)| \quad (7)$$

Energy distribution of similarity can be denoted by the Gaussian probability density function:

$$f(l_h(u,v)|l_l(u,v)) \propto \frac{1}{\sigma_n(u,v)}\exp\left(-\frac{s(u,v)^2}{2\sigma_n(u,v)^2}\right) = \frac{1}{\sigma_n(u,v)}\exp\left(-\frac{|\nabla \ln l_h(u,v) - \nabla \ln l_l(u,v)|^2}{2\sigma_n(u,v)^2}\right) \quad (8)$$

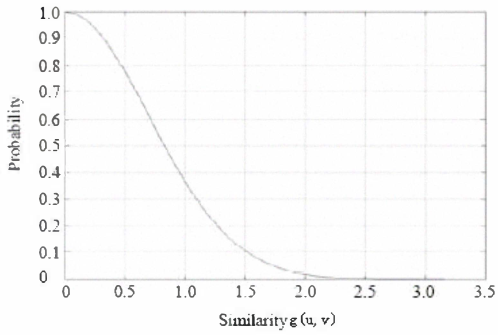



Figure 2. Gaussian probability density function

In conclusion, we can get the model of tone mapping as follows:

$$\max f(I_l|I_h) \propto \max \prod_{u,v} f(l_h(u,v)|l_l(u,v)) f(l_l(u,v))$$

$$\propto \max \prod_{u,v} \frac{1}{\sigma_n(u,v)}\exp\left(-\frac{|\nabla \ln l_h(u,v) - \nabla \ln l_l(u,v)|^2}{2\sigma_n(u,v)^2}\right) \times \frac{1}{l_l(u,v)\sigma_e(u,v)}\exp\left(-\frac{(\ln l_l(u,v)-\mu(u,v))^2}{2\sigma_e(u,v)^2}\right)$$

To every pixel, $\sigma_n(u,v)$ and $\sigma_e(u,v)$ are constant, so:

$$\max f(I_l|I_h) \propto \max \prod_{u,v} \exp\left(-\frac{|\nabla \ln l_h(u,v) - \nabla \ln l_l(u,v)|^2}{2\sigma_n(u,v)^2}\right) \times \frac{1}{l_l(u,v)}\exp\left(-\frac{(\ln l_l(u,v)-\mu(u,v))^2}{2\sigma_e(u,v)^2}\right)$$

$$\propto \min \sum_{uv} \left(|\nabla \ln l_h(u,v) - \nabla \ln l_l(u,v)|^2 - \ln l_l(u,v) + \lambda(u,v)(\ln l_l(u,v) - \mu(u,v))^2\right) \quad (9)$$

where $\lambda(u,v)$ is Lagrange multiplier.

We can further convert it to an energy minimum process based on variational problem.

$$\min E(I_l) \min \sum_{uv} \left(|\nabla \ln l_h(u,v) - \nabla \ln l_l(u,v)|^2 - \ln l_l(u,v) + \lambda(u,v)(\ln l_l(u,v) - \mu(u,v))^2\right) \quad (10)$$

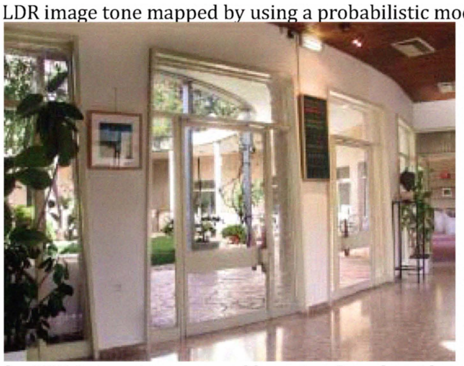
Finally, to generate LDR images that contain more information, we calculate the luminance $l_l(u,v)$ of every pixel by the minimum $E(I_l)$.

$$L(I) = \arg\min_{l_l(u,v)} E(I_l) \quad (11)$$

## III. EXPERIMENT RESULT

Figure 3 is a bathroom HDR image. The LDR image tone mapped by using a probabilistic model that proposed by SONG Ming-Li and his colleagues works well for the bright pixels but miss the information under the mirror. In the right image got from our algorithm, the lights map well and nature, even the diffuse reflection below the mirror also get better visual performance.

(a) :the LDR image tone mapped by using a probabilistic model



(b): the LDR image tone mapped by using Our algorithm

Figure 3. the LDR image tone mapped by using a probabilistic model (a), and Our algorithm (b).

## IV. CONCLUSION

High Dynamic Range Image (HDRI) is suitable for the real image, but its capture and display will require high end product with high price. For the common display and printer device, the HDR image must be transferred to Limited Dynamic Range (LDR) image. The LDR image tone mapped by using a probabilistic model that proposed by SONG Ming-Li and his colleagues work well. In this paper, we present an improved tone mapping algorithm based on a new function. The experiments on several HDR images demonstrate its super performance.

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