Optik 126 (2015) 1407–1410

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Local detail preserved exposure fusion with realistic brightness

Kuo Chen, Zhihai Xu, Huajun Feng*

State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, 310027, China

ARTICLE INFO

Article history:
Received 3 March 2014
Accepted 14 April 2015

Keywords:
Exposure fusion
High dynamic range
Detail preserving
Brightness distribution

ABSTRACT

Exposure fusion is an effective method to depict a high dynamic range scene in a single image, but the contradiction still remains: conforming to real brightness distribution of target scene and preserving local details within different luminance. A detail preserved fusion algorithm with realistic brightness is proposed in this paper to balance the contradiction. A new piecewise well-exposedness evaluation function is introduced to avoid the possible luminance reversion and loss of details under extreme high and low brightness. Furthermore, the proposed global brightness control function insures more real brightness distribution of blended image. Then local edges and textures are preserved by proposed local detail preserved function. The experimental results show that our algorithm represents more details than some commonly used algorithms. In the view of appreciation, our approach could show a more real brightness distribution of target scene.

1. Introduction

Capturing natural scenes in a single photograph cannot reflect the whole details within a wide range of luminance [1]. The reason for this phenomenon is that the dynamic range of natural scenes exceeds what the image sensor can handle at once [2]. Actually, our objective is to show a high dynamic range (HDR) target scene in a low dynamic range (LDR) image.

To settle this issue, researchers have obtained many achievements [3–11]. An effective fusion method was firstly proposed by Mertens et al. [12]. Based on Laplacian pyramid, they computed the desired image by keeping only the 'best' pixel region. However, their algorithm would make the pixel value of fused image as a whole approach to median. Vanmali et al. [14] designed a single weighting function to estimate whether the pixel was 'good', which was much faster than [12]. But this simple fusion would result in sever halos and decline of contrast in final fused images. Based on photography, Reinhard et al. [6] proposed a simple and well-suited tone-mapping. To preserve more details, bilateral filter was also applied in tone mapping.

However, all these aforementioned methods did not take the real brightness distribution of HDR scene into consideration. In other words, the final blended images are possible to contain luminance reversion. To solve this, Li et al. [10] divided input image into base layer and detail layer by bilateral filter. However their algorithm involved a more computational cost because of bilateral filter. Similarly, Duan et al. [7] used histogram adjustment to avoid luminance reversion and reveal more details, but their method needed to recover HDR radiance maps beforehand.

Aiming at those problems, we design a piecewise well-exposedness evaluation function. In the discrete wavelet transform (DWT) domain, we ensure realistic brightness and local texture further through proposed global brightness control function and local detail preserved function.

2. Exposure fusion

2.1. Piecewise well-exposedness evaluation function

Normalize the pixel values of image sequence $\{L_i\}$ into 0-1, where i indicates the order number. We define the 'optimum exposed value', when one pixel value is close to 'optimum exposed value', it means this pixel is 'good'. Firstly, we design the following piecewise well-exposedness evaluation function w_p:

$$w_p = \begin{cases} e^{-(((g_i-1/6)^2)/2\sigma_d^2)}, & 0 \le g_i \le 1/3 \\ e^{-((g_i-1/2)^2/2\sigma_m^2)}, & 1/6 \le g_i \le 5/6 \\ e^{-((g_i-5/6)^2/2\sigma_b^2)}, & 2/3 \le g_i \le 1 \end{cases} \quad (1)$$

$$3\sigma_d = \max\left|g_i - 1/6\right|, 3\sigma_m = \max\left|g_i - 1/2\right|, 3\sigma_b = \max\left|g_i - 5/6\right| \quad (2)$$

* Corresponding author. Tel.: +86 57187951182.
E-mail address: fenghj@zju.edu.cn (H. Feng).

http://dx.doi.org/10.1016/j.ijleo.2015.04.030
0030-4026/

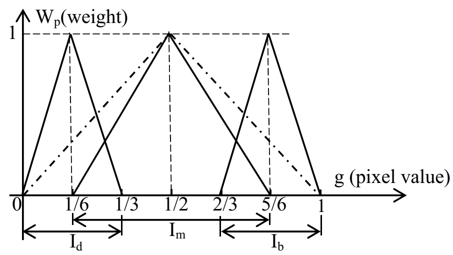

Fig. 1. Physical significance of well-exposedness function.

where g_i denotes normalized pixel values of image L_i, σ_d, σ_m, σ_b refine the function and Eq.2 describes their values. As shown in Fig. 1, the solid line depicts physical significance of PWEEF. Based on pixel values image $L_i$is divided into three overlapped regions I_d, I_m, I_b. And we define the 'optimum exposed value' of dim region I_d as 1/6, 1/2 and 5/6 for medium region I_m and bright region I_b, respectively.

As shown in Fig. 1, the dot dash line shows the traditional single 'optimum exposed value' [12], which must results in inconformity of brightness distribution. To settle this, Li et al. [10] calculated the global average brightness of LDR images by bilateral filter. Coincidentally, we propose the multiple 'optimum exposed value' strategy. Thus, the final fused image will be close to HDR scene with realistic brightness.

Setting the 'optimum exposed value' as 0.5, its essence is keeping these details whose pixel values are around 0.5 [12]. However, not all the objects can satisfy this premise. Lee et al. [15] thought that objects with different brightness have their own vital detail, which is also the basis of our proposed PWEEF. The proposed multiple one can take target details under different brightness into account.

2.2. Global brightness control function

Based on the whole LDR images with different exposedness, we propose the global brightness control function. Referring to Duan et al. [7], we calculate the average brightness mL_i of image L_i in LDR image sequence $\{L_i\}$:

$$ml_i = \exp\left[\frac{1}{M}\sum_{\Omega_{L_i}}\log\left(L_i(x,y)+\varepsilon\right)\right], \quad i = 1, 2, \ldots N \tag{3}$$

where M indicates the total pixel numbers, Ω_{L_i} indicates the spacial domain of image L_i, $L_i(x,y)$ is brightness of image L_i, small value ε is used to avoid the singularity, N is the total numbers of LDR image sequence.

Because of limitation on the bits of digit image, when average brightness mL_i increases, the pixel values of over-exposed image regions will still be 255 (assumed to be 8-bit). As a result, this paper carries out the following global brightness control function (GBCF) w_g, which gives larger weight to image with larger average brightness mL_i and offsets the limitation of finite bits.

$$w_g = \frac{ml_i}{\sum_{i=1\to k} ml_i} \tag{4}$$

2.3. Local detail preserved function

During the fusion procedure, it is necessary to take local detail information into consideration. Considering a pixel in image L_i, and Ω denotes its neighborhood. Generally, variance of pixel values in Ω is used to represent the local details around it. However it will lead to more computational cost, we suggest the approximate local variance $\widehat{D}$:

$$\hat{D} = \left|L_i - F_m\left\{L_i\right\}\right| \tag{5}$$

where F_m denotes mean filtering in each pixel's neighborhood. As a result, the variance $D_{(x,y)}$ of every pixel in image L_i can be calculated and then we build this local detail preserved function w_l:

$$w_l = \exp\left(-\frac{\left\|D_{(x,y)} - \max\left\{D_{(x,y)}\right\}\right\|^2}{2\sigma_l^2}\right) \tag{6}$$

$$\sigma_l = \frac{\max\left\{D_{(x,y)}\right\} - \min\left\{D_{(x,y)}\right\}}{3} \tag{7}$$

where σ_l refines the LDPF w_l and is calculated by $D_{(x,y)}$ adaptively. The LDPF aims at giving larger weights for these regions with more edges and textures.

2.4. Exposure fusion

In this paper, exposure fusion is realized in the discrete wavelet transform domain. The wavelet pyramid of image L_i is denoted by P_i^l, where i is the sequence number, l is the pyramid level.

$$P_i^l = \left[HH_i^j, HL_i^j, LH_i^j, \cdots LL_i^l\right], \quad i = 1, 2, \cdots N; \; j = 1, 2, \cdots l \tag{8}$$

where HH_i^j, HL_i^j, LH_i^j denote diagonal, horizontal and vertical details of j-th level pyramid respectively, LL_i^l denotes DC components of l-th level pyramid.

As what mentioned before, we can get PWEEF $w_{p,i}$, GBCF $w_{g,i}$ and LDPF $w_{l,i}$ for a specific image in LDR image sequence $\{L_i\}$, totally $3N$ weight maps. To obtain a consistent result, we normalize the weight maps

$$\begin{bmatrix} w\_n_{p,i} \\ w\_n_{g,i} \\ w\_n_{l,i} \end{bmatrix} = \frac{\left[w_{p,i} \quad \sqrt{w_{g,i}} \quad \sqrt{w_{l,i}}\right]^T}{\sum_{i=1\to N} w_{p,i}\cdot w_{g,i}\cdot w_{l,i}} \tag{9}$$

obtaining normalized well-exposedness map $w\_n_{p,i}$, global brightness map $w\_n_{g,i}$ and local detail map $w\_n_{l,i}$. Using the square roots of $w_{g,i}$ and $w_{l,i}$ means that they take a smaller weight. For each weight maps, we establish their Gaussian pyramid and the j-th level pyramid is denoted by $w_{p,i}^j$, $w_{g,i}^j$ and $w_{l,i}^j$, respectively. At last the new fused wavelet pyramid $\hat{P}_i^l$ can be obtained by a weighted blending of P_i^l:

$$\hat{P}_i^l = \begin{bmatrix} w_{p,i}^j \cdot w_{l,i}^j \cdot HH_i^j, \\ w_{p,i}^j \cdot w_{l,i}^j \cdot HL_i^j, \\ w_{p,i}^j \cdot w_{l,i}^j \cdot LH_i^j, \\ \cdots, \\ w_{p,i}^j \cdot w_{g,i}^j \cdot LL_i^j \end{bmatrix}, \quad \begin{matrix} i = 1, 2, \ldots N \\ j = 1, 2, \ldots l \end{matrix} \tag{10}$$

In conclusion, a wavelet pyramid sequence $\left\{P_i^l\right\}$ can be obtained for the LDR image sequence $\{L_i\}$. The new wavelet pyramid sequence $\left\{\hat{P}_i^l\right\}$ is obtained and used to calculate the final fused image Fu_L by IDWT:

$$Fu\_L = \mathrm{IDWT}\left\{\sum_{i=1\to N}\hat{P}_i^l\right\} \tag{11}$$