2D Denoising Factor for High Dynamic Range Imaging

Zijian Zhu, Zhengguo Li, and Susanto Rahardja*
Institute for Infocomm Research

Pasi Fränti†
University of Eastern Finland

Figure 1: *HDR image generated by using (a) Debevec and Malik 1997, (b) Yao et al. 2010, (c) Akyuz and Reinhard 2007, and (d) the proposed method which not only generates better result than method (c) but also uses only 1/5 of its processing time.*

1 Introduction

The presence of noise in a high dynamic range (HDR) synthesis poses a serious degradation to the HDR image especially when the input images are captured at low light condition or with high sensitivity settings. Thus, a two-dimensional (2D) denoising factor is proposed to assign higher weight to a pixel with less noise based on both pixel luminance and image exposure. This pure temporal denoising factor is controlled by two key coefficients and can preserves edge and fine detail without blurring artifact. In addition, both memory and computation time are significantly reduced compare to other denoising methods.

2 Our Approach

The first dimension of the proposed denoising factor assigns a high weight to a pixel with a large luminance. Given an assumption that the noise distribution is independent of the measurement pixel value z, [Mitsunaga and Nayar 1999] argued that a luminance based weighting function (MN weight) of $\omega = f(z)/f'(z)$ will achieve the best signal to noise ratio, where $f(z)$ is the radiometric response function. [Akyuz and Reinhard 2007] modified the MN weight by replacing pixel value with luminance value. A broad hat function $h(z) = 1 - (2z/255 - 1)^{12}$ was used to restrict the saturated pixels which may cause color cast. Since the radiometric response function is usually monotonic increasing, we approximate the luminance based weight by a controllable hat function and a Hermite interpolation. Thus, we can significantly reduce processing time on response function recovery by defining a new weighting factor as

$$\omega(z) = \begin{cases} 1 - |\frac{z}{\beta} - 1|^{\alpha}, & 0 \le z < \beta \\ 1 - 3(\frac{255-z}{255-\beta})^2 + 2(\frac{255-z}{255-\beta})^3, & \beta \le z < 255 \end{cases}, \quad (1)$$

where two key coefficients are the denoising strength coefficient α and the saturation control coefficient β. It can be seen the smaller the value of α, the hat function will be steeper and this will result in better denoising effect. A large α gives high weights to small value (luminance) pixels, which keeps noise in the synthesized HDR image. We choose $\alpha = 2$ in the experiments. And test also shows that $\alpha = 12$ generates similar result as [Akyuz and Reinhard 2007]. The saturation control coefficient limits the near saturated pixels to avoid color cast due to gamut limitations (an empirical value $\beta = 200$ is used here).

The second dimension of the proposed denoising factor is based on exposure time. More photons reach the camera sensor with a longer exposure time (Δt), which results in a more accurate reading. Thus, the proposed 2D weighting factor is designed to multiply the geometrically normalized exposure times with the luminance based denoising factor as

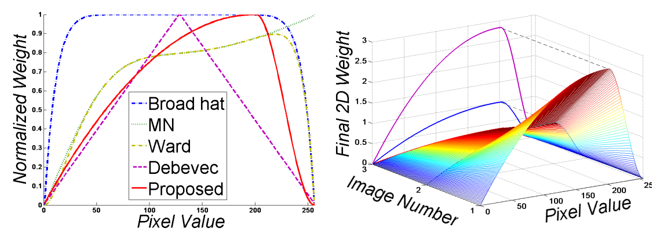

Figure 2: *(Left) The proposed luminance based weighting compares to other weighting functions; (Right) An example of the proposed 2D denoising factor with 3 input images.*

$$W(z, \Delta t_j) = \sqrt{\Delta t_j / \sqrt[P]{\prod_{p=1}^{P} \Delta t_p} \cdot \omega(z)}, \quad (2)$$

where j denotes the jth image in the total P input images. The geometrical normalization avoids overwhelming big weights caused by some very large exposure time. Then, the objective function,

$$\begin{aligned} O = & \sum_{i=1}^{N} \sum_{j=1}^{P} \{W(z, \Delta t_j)[Z_{ij}) - \ln E_i - \ln \Delta t_j]\}^2 \\ & + \lambda \sum_{z=Z_{min}+1}^{z=Z_{max}-1} [W(z, \max(\Delta t_1, ..., \Delta t_P)) g''(z)]^2, \end{aligned} \quad (3)$$

is used to calculate camera response function (g) and synthesize the clean HDR image.

The proposed denoising method is verified by comparing it with three HDR synthesis methods. The noise is significantly reduced as compared to [Debevec and Malik 1997] with the same processing time. No blur artifact is generated as [Yao et al. 2010] and they are achieved due to spatial averaging. Comparing with [Akyuz and Reinhard 2007], the quality of the proposed is about the same. However, the proposed is achieved with only 1/5 of the processing time, since no intermediate steps for approximating response function is required.

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*e-mail: {zhuzj, ezgli, rsusanto}@i2r.a-star.edu.sg
†e-mail: franti@cs.joensuu.fi

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