Subset Noise Bias Compensation for Tone-mapping and Up-scaling of JPEG Images

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***Abstract*— The super resolution technique plays an important role in displaying a conventional low resolution (LR) image on a recently developed high resolution (HR) display. In its process, some of enhancement techniques such as de-noising, de-blurring and tone-mapping are combined to increase visual quality. This paper introduces a subset noise bias compensation (NBC) to an LR-to-HR up-conversion process which is composed of tone-mapping and up-scaling. In our system, 1) an LR image is encoded and decoded with JPEG, 2) pixels in the decoded noisy image are tone-mapped, 3) observed pixel values are classifies into subsets and the bias of each subset is compensated with an optimally designed compensation value, and 4) the images are up-scaled with a state-of-the-art super-resolution technique. Improvement by the proposed method is confirmed with PSNR and SSIM evaluation measures, respectively.**

Keywords—super resolution, compression, image coding, tone-mapping, up-scaling

I. INTRODUCTION

So far, various up-scaling techniques have been reported [1,2]. They play an important role in displaying a conventional low resolution (LR) image on a recently developed high resolution (HR) display such as 4K TV [3]. In its up-conversion process, some of enhancement techniques such as de-noising, de-blurring and tone-mapping are combined to increase visual quality of displayed images in electric appliances. This paper introduces a subset noise bias compensation (NBC) to an LR-to-HR up-conversion process to increase visual quality of tone-mapped and up-scaled images.

An up-scaling technique interpolates an unknown pixel between neighboring given pixels in a still image or a video frame [1-3]. It has been utilized to reduce the memory band width in data compression. An HR image is down-scaled to an LR image before encoding and up-scaled to HR after decoding the LR image in [4,5]. This kind of down-sampling based coding (DBC) have been adjusted to the H.264 international standard in [6,7].

To furthermore increase visual quality, tone-mapping techniques can be combined. The histogram equalization stretches contrast of images [8]. The L2 norm minimization of the tone-mapping function was introduced in the two-layer image coding [9]. The nonlinear sensitivity to the coding noise was considered for the High Efficiency Video Coding (HEVC) international standard [10].

In this paper, we consider a system which includes both of the up-scaling and the tone-mapping. In the system, 1) an LR image x is encoded and decoded with the JPEG international standard as illustrated in Figure 1. Note that pixel values in the decoded image v contain the quantization noise added by the JPEG coding. Secondly, 2) pixels in the decoded noisy image v are tone-mapped to the image y. Finally, 3) the image y is up-scaled by a super-resolution in [1] to generate the HR image w.

This paper aims at reducing the noise included in the output HR image w introducing the subset noise bias compensation (NBC). In this technique, the bias (the mean) of pixel values in each subset is compensated with an optimally designed compensation value. Note that primitive idea of NBC was reported in [11]. It was not designed for the system in Figure 1, and it requires a hyper parameter to be experimentally determined. In this paper, a closed form optimum solution of the compensation function for this system is provided. Effectiveness of the proposed method is experimentally investigated with the peak signal to noise ratio (PSNR) and the Structural SIMilarity (SSIM) index [12] for evaluation of the output HR image quality.

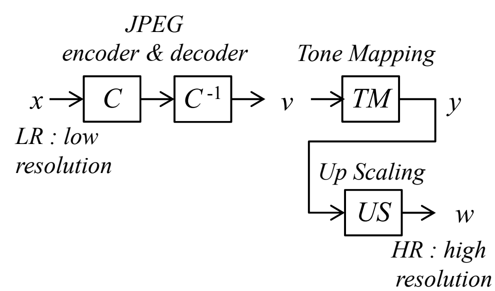


Figure 1 The system discussed in this paper. An input low resolution image x is coded with JPEG followed by tone-mapping and up-scaling to generate the output high resolution image w.

II. TONE-MAPPING, UP-SCALING AND JPEG CODING

After encoding and decoding with the JPEG international standard data compression algorithm, an integer pixel value v contains the quantization noise q, namely,

$$v = x + q, \quad v, x \in [0, 2^8) \in Z \tag{1}$$

where x denotes an integer pixel value of the original LR image. It is tone-mapped with a function f as

$$y = Tm(v) = R[f(v)], \quad y \in [0, 2^8) \in Z \tag{2}$$

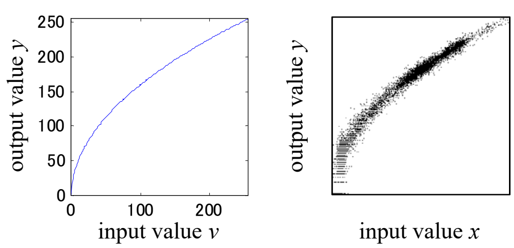
where $R[\ ]$ denotes rounding to integer and clipping into the range of $[0,2^8)$. An example of the tone-mapping based on the power function (Gamma) is illustrated in Figure 2. An integer v is mapped to an integer y in Figure 2(a). In this paper, we are considering the quantization noise q which is expressed as a stochastic variable. Figure 2(b) illustrates relation between x and y. It indicates that an observed value y is mapped from various different values of x. This fact is utilized in NBC of the proposed method. Figure 3 illustrates an example of the histogram equalization (HistEQ). The tone-mapping function is designed according to the histogram of the input pixel values as

$$f(u) = \frac{\sum_{x=0}^{u} H(x)}{\sum_{x=0}^{255} H(x)} \cdot 255 \tag{3}$$

where $H(x)$ denotes the histogram of the pixel value x. In Figure 1, the tone-mapped image is up-scaled with a super resolution algorithm. In this paper, we use the Iterative Curvature Based Interpolation (ICBI) in [1]. Finally, we have a pixel value w of the output HR image as

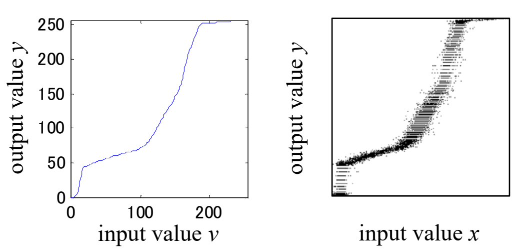
$$w = Us[y] \tag{4}$$

where $Us[\ ]$ denotes a converted pixel value by the up-scaling. Note that a result of this conversion depends on not only the input pixel value but also its location in the image.



(a) (b)

Figure 2 An example of the tone-mapping based on the power function $f(x)=x^{1/2}$ (Gamma).



(a) (b)

Figure 3 An example of the tone-mapping based on the histogram equalization (HistEQ) designed for the ‘Cameraman’ image.

This paper aims at reducing the variance of the output noise defined as

$$\Delta w = Us[y] - Us[Tm(x)] \tag{5}$$

under the assumption that it can be approximately attained by reducing the variance of

$$\Delta y = y - Tm(x) \tag{6}$$

which means difference between two tone mapped pixel values. One is y which includes the quantization noise and the other is $Tm(x)$ which does not include the noise.

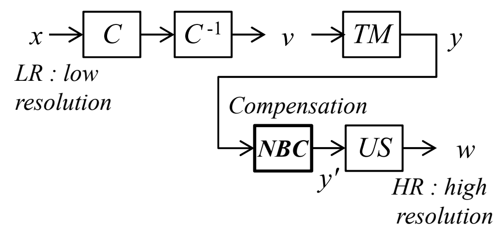


Figure 4 In the proposed method, the subset noise bias compensation (NBC) is applied to y so that the noise in w is reduced.

III. Subset Noise Bias Compensation

As illustrated in Figure 4, the subset noise bias compensation (NBC) is introduced in the proposed method. Firstly, a pixel in the noisy image after the tone-mapping is classified into a subset according to its pixel value y. Namely, all pixels in a subset have the same observed value. Secondly, the bias (the arithmetic mean) of the subset is subtracted from the pixel value so that the bias of each subset (subset bias) is compensated. As a result, the variance of the noise in the output HR image is reduced after NBC.

In this paper, we estimate the subset bias using the joint probability density function $P(x,y)$ of x and y. The estimate is calculated as

$$h_c(y) = \frac{\sum_x P(x,y)\{y - Tm(x)\}}{\sum_x P(x,y)} \tag{7}$$

and the pixel value y in Figure 4 is compensated as

$$y' = y - h(y) \tag{8}$$

where

$$h(y) = R[h_c(y)], \quad h(y) \in Z \tag{9}$$

before the up-scaling to generate the HR output image. Figure 5 illustrates the compensation function $h(y)$ calculated from (7) and (9) for each of the examples in Figure 2 and Figure 3. The compensation function values in (9) is included into the bit stream (compressed data) of the JPEG encoder. However its data volume is negligible since this is a 1D integer to integer mapping table and its length is 256. The function $P(x,y)$ is investigated before preparing the table. Note that $P(x,y)$ is not necessary to be included into the bit stream.

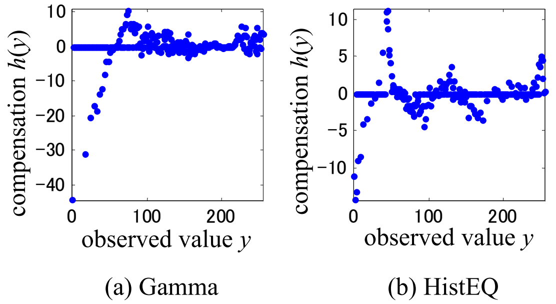


Figure 5 The compensation function $h(y)$ obtained by the proposed method for each of the tone-mapping examples in Figure 2 and Figure 3.

The rationale of the calculation in (7) is explained as below. We are reducing the cost function defined as

$$I = \sum_y \sum_x \{y - h_c(y) - Tm(x)\}^2 P(x, y) \qquad (10)$$

so that the variance of the compensated value y' and the desired value $Tm(x)$ denoted as

$$\Delta y' = y' - Tm(x) \qquad (11)$$

is reduced. Using the least mean square minimization, the optimum function h is obtained from

$$\sum_x \{y - h_c(y) - Tm(x)\} P(x, y) = 0\,. \qquad (12)$$

As a result, the calculation in (7) is derived.

IV. Experimental Results

Effect of introducing NBC on reducing the noise in (5) is investigated. The input LR image is produced from SIDBA image set with 2:1 down-scaling with an anti-aliasing filter. Figure 6 summarizes the variance measured with PSNR for the 'HistEQ' tone-mapping. The standard deviation (STD) of the quantization noise q in (1) is set to 10 as an example. Comparing to the method mentioned in Figure 1, the 'proposed' method in Figure 4 increases PSNR from 20.56 to 21.33 [dB] for 'Couple' at the maximum. In average over all tested images, PSNR is increased from 22.58 to 23.00 [dB]. Figure 7 indicates distortion of the output HR image measured with SSIM [12]. It was observed that the proposed method increases SSIM from 0.55 to 0.60 at the maximum for 'Couple'. Figure 8 and 9 indicates PSNR and SSIM for the 'Gamma' tone-mapping, respectively. It was observed that the proposed method increases PSNR from 29.64 to 30.30 [dB] and SSIM from 0.82 to 0.84 in average. The proposed method has positive effect on all tested images.

Figure 10 and 11 indicates PSNR and SSIM for 'Cameraman' at various levels of the quantization noise q in (1), respectively. The 'Gamma' tone-mapping in Figure 2 is used as an example. It was observed that the more the noise variance is, the more the proposed method improves the output HR image quality in both of PSNR and SSIM.

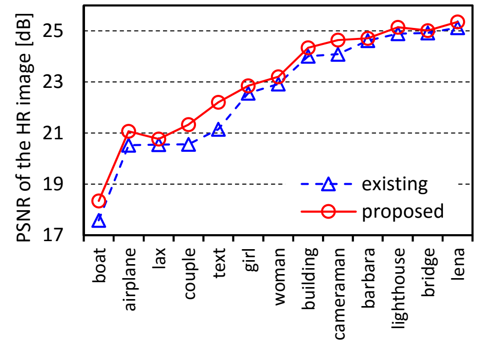


Figure 6 PSNR of HR images for 'HistEQ' tone-mapping.

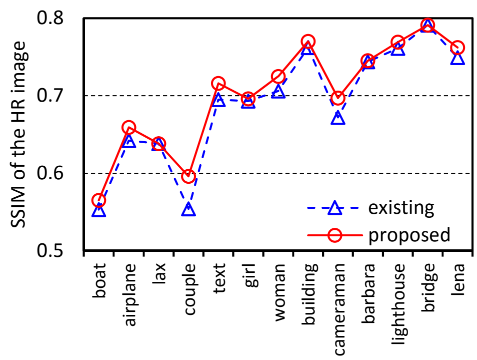


Figure 7 SSIM of HR images for 'HistEQ' tone-mapping.

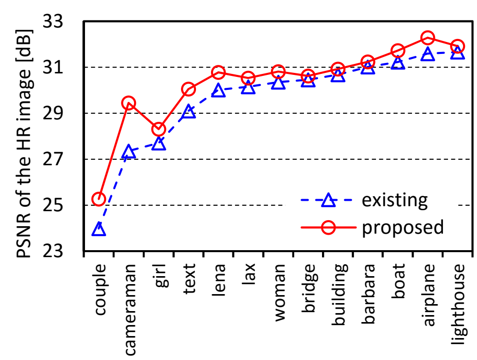


Figure 8 PSNR of HR images for 'Gamma' tone-mapping.

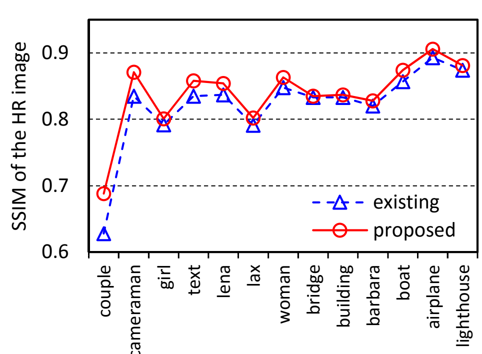


Figure 9 SSIM of HR images for 'Gamma' tone-mapping.

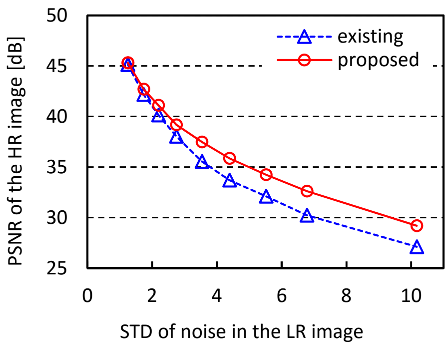


Figure 10 PSNR of the HR image at various quantization noise levels.

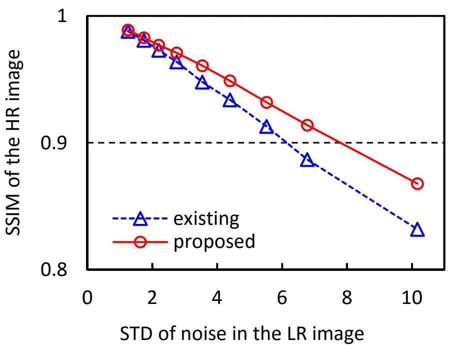
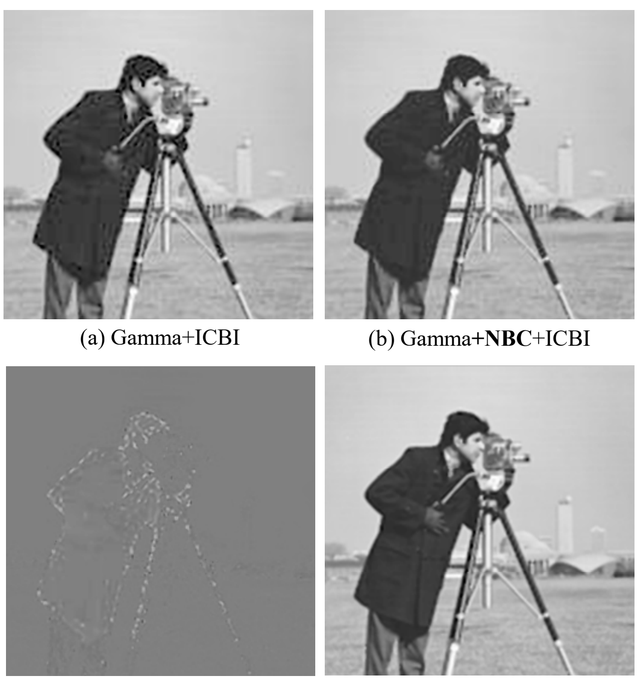


Figure 11 SSIM of the HR image at various quantization noise levels.



(a) Gamma+ICBI (b) Gamma+**NBC**+ICBI

(c) Difference (d) without noise

Figure 12 The output HR image examples for 'Cameraman'.

Figure 12 indicates output HR images at STD=5 in Figure 10 and 11. Comparing to the image of the existing method in Figure 12(a), quality of the image of the proposed method in Figure 12(b) is improved from 32.23 to 34.51 [dB] in PSNR and from 0.92 to 0.94 in SSIM, respectively. Figure 12(c) indicates the difference between these two images. Figure 12(d) indicates the tone-mapped and up-scaled image from the original LR image x (down-scaled SIDBA image).

V. Conclusions

In this paper, the subset noise bias compensation was introduced to the up-conversion system which is composed of the tone-mapping and the up-scaling. The compensation function of NBC is designed so that it reduces noise added to the output high resolution image of the system. It was experimentally confirmed that the proposed method has positive effect on all the tested images. Since the investigation is limited to monochrome images, it should be extended to color images in the near future.

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