BIT-LENGTH EXPANSION BY INVERSE QUANTIZATION PROCESS

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ABSTRACT

Color bit-length (i.e., resolution of signal amplitude) is an important attribute to image quality. The bit-length is decided by the quantization of image capture devices. The precision in various image capture devices limits the color bit-length and introduces loss in visual quality. Expanding the bit-length is important image enhancement issue. For example, the bit-length expansion technique is necessity for the high-quality display such as the liquid crystal display (LCD) and the plasma display. Since, these displays have more the 10-bit resolution for each color component. However, in general, color image signals are defined by 8-bit resolution for each component. Moreover, the bit-length expansion technique is also necessary for low bit-length captured images. If we expand bit-length of these images by using most bit-length expanding algorithms, pseudo contouring effect is observed in smooth gradient area. The bit-length expansion process and inverse quantization process are equivalent. Inverse quantization is able to perform by suitable filtering. In this paper, the bit-length expansion method using a nonlinear filter with adaptive window size is proposed. We show the excellent bit-length expanded results are obtained by the proposed method.

Index Terms— bit-length expansion, pseudo contour, adaptive window size filtering

1. INTRODUCTION

Digital images are commonly used nowadays. Bit-length is number of the bits used to represent a pixel value in digital images. Bit-length conversion is very important in the field of image processing. There are many methods are proposed to convert high bit-length images to low bit-length images including tone mapping, dithering and half-toning [1]. However, there are not so many researches on the important problem of image bit-length expansion.

In various imaging systems, different capture, storage and display devices are used. In some low-end devices, only few bits are used to represent each color component. For example, a webcam typically captures 16-bit for three color components. With limited color precision, the color bit-length of the displayed image is restricted. This leads to false edges in smooth regions. The bit-length expansion technique is necessary for displaying low bit-length images on high-quality display. Moreover, the bit-length expansion technique is necessity for the high-quality display (i.e., LCD and the plasma display). Since, these displays have more the 10-bit resolution for each color component. However, in general, color image signals are defined by 8-bit resolution for each component.

A common bit-length expansion method is zero padding in which zero bits are appended to the low-bit signal to form the LSBs of the bit-expanded signal. Another method is multiplication-by-an-ideal-gain (MIG) [2]. Bit replication [2] is another method in which the MSBs of the low-bit signal are appended to the low-bit signal to form the bit-expanded signal. These three are simple methods that tend to pseudo contouring problem.

Inverse halftoning is another class of methods to increase the bit-length. They convert halftoning images with a 1-bit to regular image with 8-bit. Inverse halftoning is achieved by low-pass type filtering and many methods were proposed [3], [4]. Adaptive filtering is also applied to the bit-length expansion in [5].

In this paper, the bit-length expansion method by using edge preserving low-pass filter with adaptive window size is proposed. Low-pass filtering with large window size causes the degradation of detail part of images. On the other hand, low-pass filtering with small window size can't resolve the pseudo contouring problem. Furthermore it is not adequate to make filtering across the different smooth regions. In this paper, we use the ε-filter [6] which is one of edge-preserving filters with adaptive window size. Excellent bit-length expanded images are obtained by the proposed method.

2. PROPOSED METHOD

2.1. Algorithm overview

$x_2^p(i, j)$ is the pixel value at location (i,j) and represented a binary number with p-bit. We think about the bit-length expansion from p-bit to q-bit (i.e., $q>p$).

First, a binary number $x_2^p(i,j)$ is changed to a decimal number $x_{10}^p(i,j)$. The MIG method is applied to $x_{10}^p(i,j)$ in order to expand signal full range of the bit-length.

$$\tilde{x}_{10}^q(i,j) = x_{10}^p(i,j) \times \frac{2^q - 1}{2^p - 1} \qquad (1)$$

where $\tilde{x}_{10}^q(i,j)$ is a real number.

Next, $\tilde{x}_{10}^q(i,j)$ is applied to the proposed filtering process $F[\bullet]$. The bit-length of $\tilde{x}_{10}^q(i,j)$ is assumed to be expanded more than q-bit.

$$\hat{x}_{10}(i,j) = F\left[\tilde{x}_{10}^q(i,j)\right] \qquad (2)$$

We round $\hat{x}_{10}(i,j)$ off to the closest whole number.

$$\hat{x}_{10}^q(i,j) = Round\{\hat{x}_{10}(i,j)\} \qquad (3)$$

$\hat{x}_{10}^q(i,j)$ is a q-bit signal which is represented a decimal number. Thus, the bit-length expanded signal is derived by changing a decimal number to a binary-coded form as $\hat{x}_2^q(i,j)$

2.2. Proposed filtering process

In this section, we explain about the filtering process $F[\bullet]$ concretely.

In this process, we use the ε-filter. The output of the ε-filter with (2n+1)x(2n+1) window is given by

$$\tilde{x}_{10}^{(n)}(i,j) = \frac{\sum_{k=-n}^{n}\sum_{l=-n}^{n}[f\{\tilde{x}_{10}^q(i+k,j+l) - \tilde{x}_{10}^q(i,j)\} + \tilde{x}_{10}^q(i,j)]}{(2n+1)^2} \qquad (4)$$

where $f\{\bullet\}$ is a nonlinear function which is defined by

$$f\{\alpha\} = \begin{cases} \alpha & : \text{if } |\alpha| \le \varepsilon \\ 0 & : \text{if } |\alpha| > \varepsilon \end{cases} \qquad (5)$$

where ε is a positive constant. The ε-filter can realize the edge/detail preserving, since the filter has limited the range of values from $\tilde{x}_{10}^q(i,j) - \varepsilon$ to $\tilde{x}_{10}^q(i,j) + \varepsilon$ for filtering.

The output of proposed filtering process $F[\bullet]$ in Eq.(2) is given by

$$\hat{x}_{10}(i,j) = \begin{cases} \hat{x}_{10}^{(n_S)}(i,j) & \text{if } V_m > \mu \\ \hat{x}_{10}^{(n_L)}(i,j) & otherwise \end{cases} \qquad (6)$$

where n_S<n_L and $\hat{x}_{10}^{(*)}(i,j)$ (* means n_S or n_L) is derived by the following equation.

$$\hat{x}_{10}^{(n)}(i,j) = \begin{cases} \tilde{x}_{10}^q(i,j) + \dfrac{2^q-1}{2(2^p-1)} & \text{if } \tilde{x}_{10}^{(*)}(i,j) > \tilde{x}_{10}^q(\mathrm{i,j}) + \dfrac{2^q-1}{2(2^p-1)} \\ \tilde{x}_{10}^{(n)}(i,j) & \text{if } \tilde{x}_{10}^q(\mathrm{i,j}) - \dfrac{2^q-1}{2(2^p-1)} \le \tilde{x}_{10}^{(*)}(i,j) \le \tilde{x}_{10}^q(\mathrm{i,j}) + \dfrac{2^q-1}{2(2^p-1)} \\ \tilde{x}_{10}^q(i,j) - \dfrac{2^q-1}{2(2^p-1)} & \text{if } \tilde{x}_{10}^{(*)}(i,j) < \tilde{x}_{10}^q(\mathrm{i,j}) - \dfrac{2^q-1}{2(2^p-1)} \end{cases}$$

(*:n_S or n_L) (7)

V_m in Eq.(6) means the local variance of (2m+1)x(2m+1) window with (i,j)-centered. μ is the threshold value.

If the value V_m is larger than μ, the processed point is assumed to be located at edge/detail region. In this case, we should choose small window (i.e., n_S) for filtering in order to preserve the signal edge/detail. On the other hand, the value V_m is smaller than μ, the filter window should be chosen large (i.e., n_L) so as to remove the pseudo contouring at the smooth region.

Next, we explain about a meaning of the clipping in Eq.(7).

Figure 1 shows an example in the case of p=4 and q=6. Let $x(i,j)$ is an analog signal whose variance range is 0-1. $x_2^4(i,j)$ is 4-bit quantized signal. We focus attention on $x_2^4(i,j)$=0001 which is obtained rounded with an analog signal $x(i,j)$ whose value 1/30-1/10. We change $x_2^4(i,j)$=0001 to a decimal number and get $x_{10}^4(i,j)$=1. Then, $\tilde{x}_{10}^6(i,j)$=4.2 is derived by Eq.(1). The range of $\hat{x}_{10}(i,j)$ is restricted to 2.1-6.3. Thus, 4-bit signal $x_2^4(i,j)$

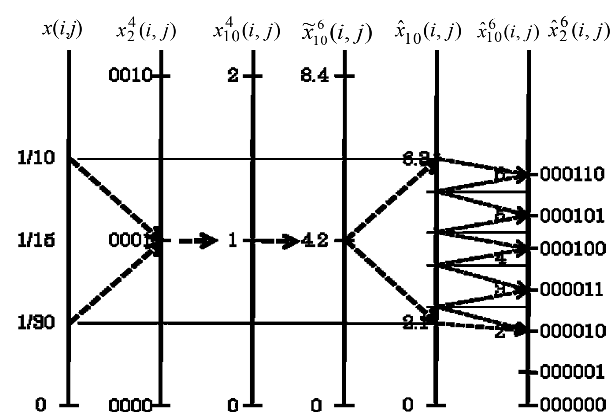


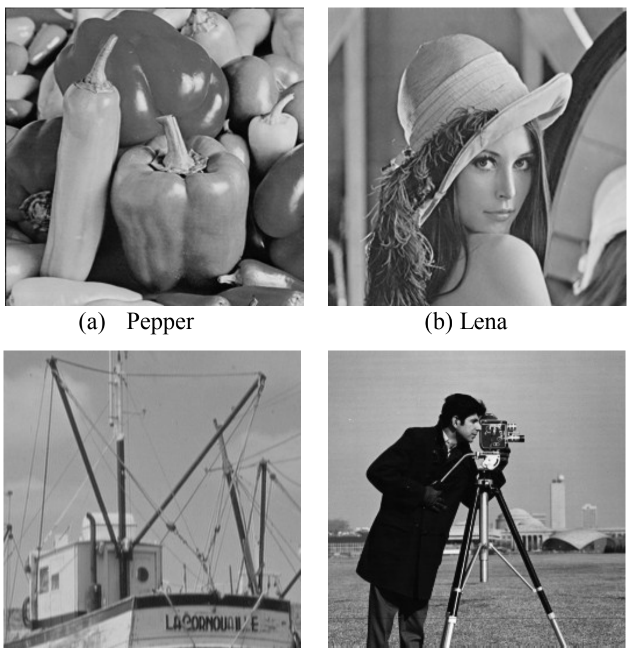
Fig.1 Bit-length expansion from 4-bit to 6-bit

=0001 is apportioned any one of $x_2^6(i,j)$=000010, 000011, 000100, 000101, 000110

2.3. Decision on the parameters of proposed method

In our method, the parameters n_S, n_L, m, and μ are needed to determine. Consider as an example the situation of increasing the image bit-length from 4-bit value to a 6-bit value (i.e., p=4, q=6). Four gray scale test images shown in Fig.2 are used for determining the parameters. The bit length and size of four images is 8-bit and 256x256 size, respectively.

Table 1 shows the peak signal to noise ratio (PSNR) between the bit-length expanded result and the original high bit-length image (i.e., 8-bit) for various parameters.



(a) Pepper (b) Lena (c) Boat (d) Cameraman

Fig.2 Test images (gray scale)

Table 1 Decision on the parameters of proposed method (PSNR: dB)

(a) Lena

	5-point cross	n_S=1	n_S=2
n_L=4	**35.80**	**35.56**	35.38
	m=3, μ =0.25	m=5, μ =0.25	m=6, μ =0.30
n_L=5	**35.73**	**35.52**	35.36
	m=3, μ =0.25	m=6, μ =0.25	m=7, μ =0.20
n_L=6	**35.62**	**35.48**	35.34
	m=4, μ =0.25	m=7, μ =0.25	m=7, μ =0.20
n_L=7	**35.59**	**35.46**	35.34
	m=3, μ =0.25	m=7, μ =0.25	m=7, μ =0.20

(b) pepper

	5-point cross	n_S=1	n_S=2
n_L=4	**36.05**	**36.12**	35.86
	m=3, μ =0.25	m=6, μ =0.25	m=7, μ =0.25
n_L=5	**35.95**	**36.09**	35.85
	m=3, μ =0.25	m=6, μ =0.25	m=7, μ =0.25
n_L=6	35.86	**36.07**	35.84
	m=3, μ =0.25	m=7 μ =0.25	m=7, μ =0.20
n_L=7	35.82	**36.05**	35.83
	m=6, μ =0.25	m=7, μ =0.25	m=7, μ =0.20

(c) boat

	5-point cross	n_S=1	n_S=2
n_L=4	**35.38**	34.87	34.82
	m=2, μ =0.20	m=3, μ =0.20	m=4, μ =0.20
n_L=5	**35.39**	34.89	34.83
	m=2, μ =0.20	m=3, μ =0.15	m=4, μ =0.20
n_L=6	**35.42**	34.90	34.85
	m=2, μ =0.20	m=3, μ =0.20	m=4, μ =0.20
n_L=7	**35.42**	34.90	34.85
	m=2, μ =0.20	m=3, μ =0.25	m=4, μ =0.20

(d) cameraman

	5-point cross	n_S=1	n_S=2
n_L=4	**35.28**	**34.76**	**34.73**
	m=4, μ =0.25	m=6, μ =0.35	m=2, μ =0.15
n_L=5	**35.30**	**34.77**	**34.77**
	m=4, μ =0.25	m=6, μ =0.35	m=2, μ =0.15
n_L=6	**35.32**	**34.79**	**34.78**
	m=4, μ =0.25	m=7, μ =0.30	m=2, μ =0.15
n_L=7	**35.34**	**34.82**	**34.80**
	m=4, μ =0.25	m=7, μ =0.25	m=2, μ =0.15

If the result of proposed method is superior to the result of ABDE-P1[5] which is excellent method using the adaptive filter, we write the PSNR value bold type.

From Table 1, small window for filtering is good to choose as 5-point cross window. n_L is 4 or 5, m=3 and μ =0.25 are suitable parameters for all images.

3. EXPERIMENTAL RESULTS

The proposed method is evaluated through experimental results. We compare the performance of following methods.

(1) Proposed method I (parameters are depend on image)
(2) Proposed method II (5-point cross window, n_L =4, m=3 and μ =0.25)
(3) ABDE-P1
(4) MIG

Table 2 shows PSNRs between the original high bit-length image (i.e., 8-bit) and the bit-length expanded images from 4-bit to 6-bit. In this Table, “4-bit” means the bit-length expanded results of the zero-padded (ZP) method.

The proposed method shows the best results of all methods. On the average, the PSNR of the proposed method is about 7dB higher than ZP and about 2dB higher than MIG for the 4-bit to 6-bit expansion. Moreover, for all images, the result of proposed method is superior to that of the ABDE-P1. This means that the performance of proposed method is very high.

Finally we show the bit-length expanded results of color images. In the color image, bit-length expansion is applied to each component (i.e., red, green and blue), independently.

Table 2 PSNR [dB] of various methods

	4-bit	Proposed I	Proposed II	ABDE -P1	MIG
Pepper	29.21	36.12	36.05	35.93	33.95
Lena	28.84	35.80	35.80	35.46	34.24
Boat	28.19	35.42	35.32	35.19	34.15
Camera	29.05	35.34	35.27	34.69	33.79

In the result of MIG, the pseudo-contour can be observed. The bit-length expanded image of ABDE-P1 shows the excellent result from the view point of objective evaluation, however the pseudo-contour is remained. The bit-length expanded image of our method is clearly and the pseudo-contour is removed

Both the subjective and objective evaluations suggest that the proposed method can suppress contours to a certain extent giving better image quality.

4. CONCLUSION

In this paper we propose a simple and efficient method using an adaptive window length filter in order to increase the bit-length of images. It provides a sharp higher bit-length contour-free image as the output. The effectiveness of proposed method is confirmed through examples.

This paper demonstrates how to increase bit-length from 4-bit to 6-bit. In fact, the proposed method can work well from different bit-length to different bit-length.

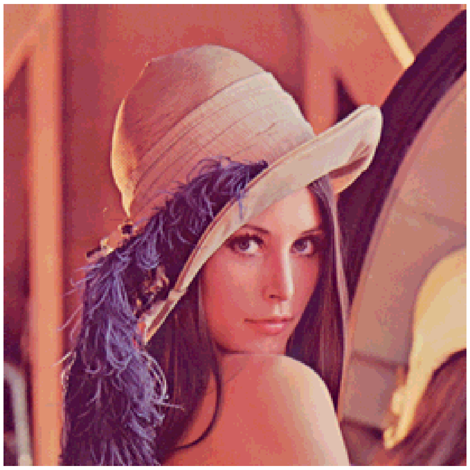
(a) 4-bit image (i.e., Zero-padded method)

(c) ABDE-P1

(b) MIG

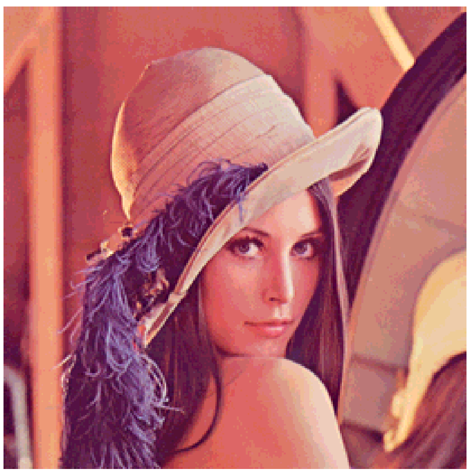
(d) Proposed method II

Fig.3 Result of various methods (Pepper)



(a) 4-bit image (i.e., Zero-padded method)

(c) ABDE-P1



(b) MIG

(d) Proposed method II

Fig.4 Result of various methods (Lena)

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