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RESOLUTION ENHANCEMENT OF DIGITAL IMAGES BASED ON INTERPOLATION WITH BIASING

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Abstract **-- Enlargement of digital image is a prime technique in the digital image processing field. Generally, an image enlargement is realized by linear interpolation method. However, the enlargement image by linear interpolation will appear blurred. The heavy blurred areas, those include high-frequency components, such as step-edges and peaks. In order to realize the edge–preserving and the peak-creating interpolation, we have introduced the concept of the warped distance among the pixels and biasing the signal amplitude, respectively. This paper presents a novel interpolation method with only biasing of the signal amplitude. The proposed method can create the peak point of concavo-convex shape signals. Furthermore, the proposed biasing method can preserve the signal edge. Thus, it is not necessary to combine the biasing and the warping.**

I. Introduction

Digital image interpolation [1] is a problem of prime importance in many fields, ranging from medical imaging to military applications or to consumer electronics. The frequency band of a digital image is decided by the specification of an input device. Thus, when we want to enlarge digital images on the display, the enlargement image is blurred.

In the idealized world of linear and stationary systems, an optimal approach for interpolation exists: the sinc function, which would permit exact reconstruction of a band-limited signal. Due to the impossibility of realizing this function physically, we derive the approximate functions as such as the bilinear and cubic interpolations. These interpolations can preserve the resolution before enlargement. However, the frequency band of enlargement image is wider than that of original image. Thus, enlargement image is blurred. The heavy blurred area in the image is the signal that is including high frequency component, for example the step-edge signals and the peak signals. The outlines in the image correspond to step-edge signals and the detail parts are constructed by the repeated small peak signals. The outlines and the detail parts are important for visually. We have already proposed a method, which is considered these signals [2]. In Ref.[2], step-edge preserving interpolation is realized by means of warping of signal coordinate[3] and peak-creating interpolation realized by the biasing of signal amplitude. And we combined these two methods.

However, the step-edge signal is regarded as a special case of the peak signals. If we can improve the methodology of the biasing method, this method can preserve not only detail signals but also step-edges. In this paper, we propose a modified biasing method, which is extended by the biasing method proposed in Ref.[2]. The proposed method preserves step-edges and the calculation amount of the proposed method is less than that of the method, which is combined biasing and warping. Thus, the proposed method is easily realized by ASIC and effective for the mobile terminal.

II. Interpolation Technique with Data-Dependent Biasing

Interpolation techniques, which are based on sinc function (i.e., bilinear and cubic interpolation), are impossible to create the peak points of concavo-convex shape signals. In Ref.[2] we have proposed the biasing method in order to create the peaks.

Figure 1 shows the concept of the biasing technique for signal amplitude, example for the twice size enlarging. The result of the bilinear interpolation shows the dashed line in Fig.1. When the peak exists between x_k and x_{k+1}, the bilinear interpolation result is smaller than the ideal result. In order to create the peaks, we add the small value to the result of bilinear interpolation.

Let $f(x_k)$ be the value at point x_k. The interpolated point x is located between x_k and x_{k+1}. The distance between x and x_k or x_{k+1} is given by $s = x - x_k$ or $1 - s = x_{k+1} - x$ $(0 \le s \le 1)$. The bilinear interpolation result is calculated by

$$\hat{f}(x) = (1-s)\cdot f(x_k) + s\cdot f(x_{k+1}). \qquad (1)$$

When twice size enlarging, $s=0.5$ because x is the center of x_k and x_{k+1}.

It is necessary for creating the peaks to increase or decrease of the value of the result of bilinear interpolation. Let $\bar{f}(x)$ be the result of the proposed interpolation with biasing the amplitude as

$$\bar{f}(x) = \hat{f}(x) + l \cdot B. \tag{2}$$

where l is constant. According to the result of Ref.[2], we set l as 0.5 in this paper. B is defined by

$$\begin{aligned} B = & \frac{C}{2} + \frac{C}{2} \cdot (A-1) \\ & \times \mathrm{sgn}\left[\{f(x_{k+1}) - f(x_{k-1})\} \times \{f(x_{k+2}) - f(x_k)\}\right] \end{aligned} \tag{3}$$

$$A = \frac{|f(x_{k+1}) - f(x_{k-1})| - |f(x_{k+2}) - f(x_k)|}{L-1} \tag{4}$$

$$C = \mathrm{sgn}\left[f(x_k) - f(x_{k-1})\right] \cdot D \tag{5}$$

where $L = 256$ for 8bits luminance images, $\mathrm{sgn}[\bullet]$ denotes the sign function. Furthermore, in Ref.[2], D is given by

$$\begin{aligned} D = \min & \left[s \cdot |f(x_k) - f(x_{k-1})|, \right. \\ & \left. (1-s) \cdot |f(x_{k+2}) - f(x_{k+1})| \right] \end{aligned} \tag{6}$$

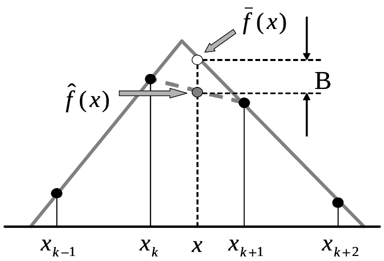
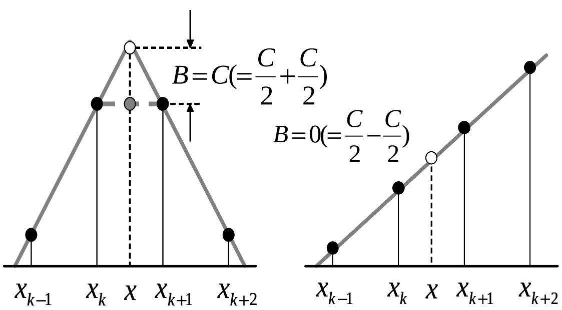


Fig.1 Interpolation with biasing of signal amplitude



(a) (b)

Fig.2 The concept of the biasing of signal amplitude

In order to explain the concept of the biasing method, we present for two type signal patterns, one is the peak signal, the other is the monotonous increasing signal as shown in Fig 2. Parameter A of these two signals is 0. Thus,

$$\begin{aligned} B = & \frac{C}{2} - \frac{C}{2} \\ & \times \mathrm{sgn}\left[\{f(x_{k+1}) - f(x_{k-1})\} \times \{f(x_{k+2}) - f(x_k)\}\right] \end{aligned} \tag{7}$$

B=0 is desired for the monotonous signal. And it is desirable that B shows maximum value for the peak signal. In the case of the peak signal, B is given as: $B = C/2 + C/2 = 0$. On other hand, for the monotonous increasing signal, $B = C/2 - C/2 = 0$. We can understand that these are the desired results.

In Eq.(6) we select minimum value of two interpolation values. However, minimum value is not adequate for all cases. Especially, if the maximum value is selected, the step-edge signal can be preserved. Therefore, in this paper, we define D as follows:

$$D = \begin{cases} \max\left[s \cdot |f(x_k) - f(x_{k-1})|, \right. \\ \quad \left. (1-s) \cdot |f(x_{k+2}) - f(x_{k+1})| \right] \\ \quad : \text{if CONDITION is satisfied} \\ \min\left[s \cdot |f(x_k) - f(x_{k-1})|, \right. \\ \quad \left. (1-s) \cdot |f(x_{k+2}) - f(x_{k+1})| \right] \\ \quad : \text{otherwise} \end{cases} \tag{8}$$

The CONDITION in Eq.(8), is assumed to be function of two values of $f(x_k) - f(x_{k-1})$ and $f(x_{k+2}) - f(x_{k+1})$ which are used in Eq.(8). We derive the CONDITION by experimental method in section III.

Next, we show how to calculate the interpolation value inside four coordinate points. The bilinear interpolated result of (x_{k+1}, y_{k+1}) is given by

$$\begin{aligned} \hat{f}(x_{k+1}, y_{k+1}) = & (1-s_x)(1-s_y) f(x_k, y_k) \\ & + s_x(1-s_y) f(x_{k+2}, y_k) \\ & + (1-s_x)s_y f(x_k, y_{k+2}) \\ & + s_x s_y f(x_{k+2}, y_{k+2}). \end{aligned} \tag{9}$$

The biasing distance B_{xy} is given by using four biasing values of B_{x1}, B_{x2}, B_{y1} and B_{y2} as follows:

$$B_{xy} = \left[(1-s_x)B_{x1} + s_x B_{x2} + (1-s_y)B_{y1} + s_y B_{y2}\right]/2 \tag{10}$$

Thus, interpolation result is given by

$$\bar{f}(x_{k+1}, y_{k+1}) = \hat{f}(x_{k+1}, y_{k+1}) + l \cdot B_{xy} \tag{11}$$

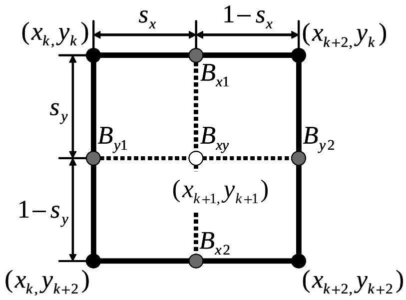


Fig. 3 Interpolation inside four coordinate points

III. Derivation of CONDITION in the Eq.(8)

The parameter D is given by Eq.(8). We should pre-determined the CONDITION in Eq.(8). We assume that the CONDITION is the function of $f(x_k) - f(x_{k-1})$ and $f(x_{k+2}) - f(x_{k+1})$. The CONDITION will be derived by the experimental method. We get the one-dimensional signal sequences by the raster scanning for both horizontal and vertical directions of the nature images and use for the experiment. Original scanned signal is decimated using the ideal half-band filter in the DFT domain. We use four images (Lena, Boat, Cameraman and Lighthouse [5]).

Figure 4 shows the integrated result of four images' simulations. Horizontal and vertical axes of this figure indicate $f(x_k) - f(x_{k-1})$ and $f(x_{k+2}) - f(x_{k+1})$, respectively. The property of the Fig.5 is symmetric with respect to the origin point. Therefore, we show the upper-half plane. This figure shows the deferential value of between two mean squared errors (MSEs). One MSE is given by the interpolated signal which is obtained by the minimum selection of Eq.(8) and the original signal. Another is given by the interpolated signal which is obtained by maximum selection of Eq.(8) and original signal.

White area means that the maximum selection is superior to the minimum selection. Gray area means that two interpolation results are almost same. Black area means that the minimum selection is superior to the maximum selection. We write in the two dashed lines on this figure. The region, which is wedged between two lines, the maximum selection is better. Thus, the region is regarded as the CONDITION of Eq.(8). We also write in two circles in Fig.4. These regions correspond to step-edge signals. We can understand that the proposed method preserves the step-edge signal, since these regions mean the maximum selection is superior to the minimum selection.

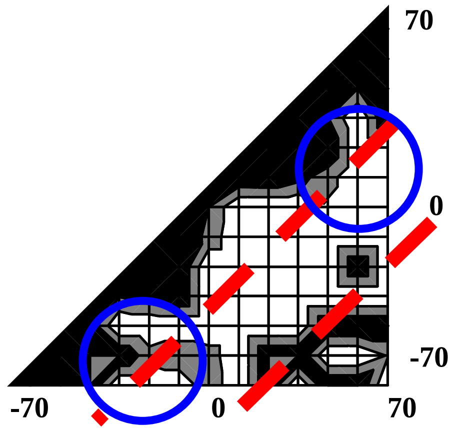


Fig. 4 CONDITION of Equation (8)

VI. Application Results of the Proposed Method

In section III, we derive the CONDITION of Eq.(8). In this section we show results of the proposed method and compare with the conventional interpolation methods. Six images (8bits and 256x256 size) are used for evaluating the interpolation performance. Four images are same images which are used in section III, and two images (Woman and Airplane [5]) are added in this section. In this simulation, the size of original images is 256 x 256 and we get the 1/2 size images by low-pass filtering and down sampling, also get the 1/4 size images by same way. And we enlarge these images to the original size, and calculate MSEs between the original image and the enlargement image. Table 1 shows MSEs of the proposed method (proposed), conventional interpolation methods (bilinear, cubic), biasing with only minimum selection (biasing) and the method of Ref.[2] (warping + biasing).

From Table 1, the performance of the proposed method is almost same as that of Ref.[2]. This means that the edge-preserve interpolation is realized by the proposed biasing method. The performance of the proposed method is better than that of the conventional interpolation methods. The results of Woman and Airplane show the effectiveness of the CONDITION. Since theses two images are not used for deciding the CONDITION.

Next, we compare the proposed method to the conventional biasing method using enlarged Lighthouse in Fig.5. Figure 5 shows two-time enlarged images and the differential images between those and the bilinear interpolation image. The differential images show the degree of the enhancement of detail parts. The enlargement image of the proposed method is clearer than that of the conventional biasing method and same as that of the combination of biasing and warping.

The computational time of Ref.[2] and the proposed method for 256x256 image, are 246[msec] and 164 [msec], respectively. We used the PC with Pentium 4 (1.8GHz). The calculation cost of the proposed method is 25% less than that of Ref.[2].

Table 1 Comparing the performance of each method

(a) Two times enlargement

	Bilnear	Cubic	Biasing	Warping +Biasing	Proposed
Lena	84.21	73.86	69.27	68.17	65.28
Lighthouse	296.5	271.8	270.6	259.8	256.2
Cameraman	199.6	175.2	169.3	162.1	161.5
Boat	78.73	66.91	68.25	61.43	65.06
Woman	79.08	67.63	69.91	72.05	68.02
Airplane	140.7	119.1	114.5	109.1	108.9

(b) Four times enlargement

	Bilnear	Cubic	Biasing	Warping +Biasing	Proposed
Lena	197.9	178.3	176.4	168.5	170.1
Lighthouse	553.5	522.3	534.9	509.6	514.9
Cameraman	455.1	418.5	413.4	401.3	393.9
Boat	226.9	198.4	200.9	189.3	191.5
Woman	198.6	175.5	175.2	176.8	171.9
Airplane	378.8	343.7	340.8	336.1	324.8

V. Conclusion

This paper presents a novel interpolation with only biasing of the signal amplitude. The proposed method can create the peak point of concavo-convex shape signals. Furthermore, the proposed biasing method can preserve the signal edge. The performance of the proposed method is confirmed to be more excellent than that of the conventional biasing and same as that of the method, which is combined biasing and warping. Since, the computational cost of the proposed method is relative low, the method is expected to be realized by the ASIC for the mobile terminal.

References

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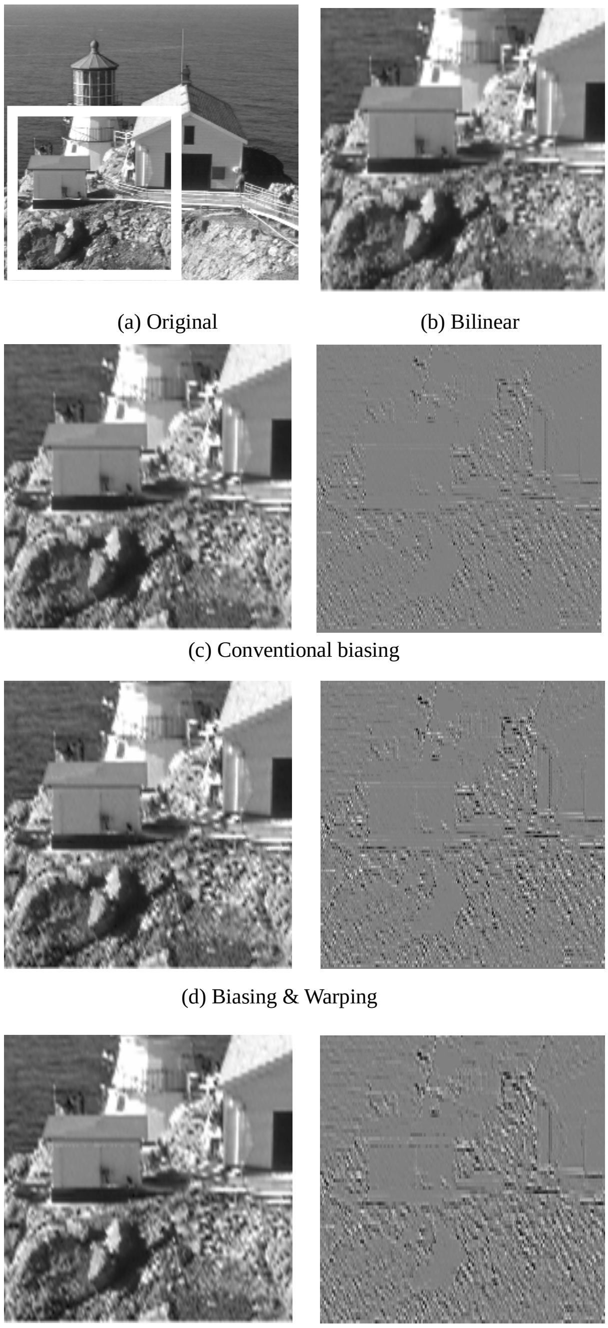

(a) Original (b) Bilinear

(c) Conventional biasing

(d) Biasing & Warping

(e) Proposed

Fig.5 Enlarged images of Lena (two-times)
(Left : Interpolation result, Right : Differential image)