Modified New Edge-Directed Interpolation Using Window Extension

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Abstract: - In this paper, we proposed modified NEDI (New Edge-Directed Interpolation) method using recursive window extension and clipping technique. The conventional NEDI interpolates HR pixels based on the geometric duality between HR (high resolution) and LR (low resolution) pixels. When the reference pixels in the window have different structures locally, the calculation of interpolation coefficients can be greatly affected. This is because when using geometric duality, pixels are used in the limited window. Also, if the structures of the reference pixels in the window are different from each other, there is a problem that the geometric duality between the HR and LR pixels is reduced and distortion occurs. In this paper, we used recursive window extension method for improving the structural similarity of the pixels in the window and clipping technique for increasing the geometric duality. Experimental results show that the results of various algorithms are compared and subjective and objective image quality is improved compared to the conventional NEDI.

1 Introduction

Image interpolation means obtaining a HR image from a LR image. The HR image is obtained by interpolating pixels between LR pixels to increase the image resolution. That is, HR pixels are generated by using LR pixels. The image interpolation technique is applied to many applications to maintain compatibility when the resolution of the image output device is different or the resolution is changed by the user.

The image interpolation algorithm can be classified into linear and nonlinear interpolation. Linear methods include bilinear interpolation and bicubic interpolation [1]. These techniques have a smaller computational complexity than the nonlinear method, but distortions occur in the resulting image after interpolation. In particular, blurring and aliasing occur near the edge region of the result image, thereby resulting in the image quality degradation.

Nonlinear methods have been proposed to reduce the degradation artifact around edges. EDI (Edge Directed Interpolation) algorithm interpolates HR pixels using zero crossing points [2]. It is a technique to predict the edge direction and interpolate by using the zero crossing point obtained based on LR pixels. Also, the NEDI using structural similarity between HR and LR was proposed [3]. This method interpolates HR pixels around edge regions,

reflecting the geometric duality between HR and LR. However, it has the demerit of misprediction if the pixels within the range considering the geometric duality contain greatly different structures. In this paper, we analyze cases artifacts occuring when interpolating with the conventional NEDI near the edge region, and introduce proposed method for minimizing the distortions.

The rest of this paper is organized as follows: an overview of the conventional NEDI is given in Section 2, and the solutions to the problems of the conventional NEDI are presented in Section 3. In Section 4, the performance of the proposed method is compared with other conventional methods through experiment results. Finally, in Section 5, we conclude the proposed algorithm.

2 New Edge-Directed Interpolation

The NEDI computes interpolation coefficients for the four pixels around a pixel to be interpolated based on geometric duality existing between HR and LR. It interpolates the HR pixels through a weighted sum technique. The geometric duality means the structural relationship between four adjacent pixels at the center of a HR pixel to be interpolated and four neighboring pixels of each LR pixel in a window. It is an interpolation technique that uses the similarity

of the structure of the four pixels around each LR pixel and of the four pixels around the HR pixel.

$$\hat{Y}_{2i+1,2j+1} = \sum_{k=0}^{1} \sum_{l=0}^{1} \alpha_{2k+l} Y_{2(i+k),2(j+l)} \qquad (1)$$

Equation (1) shows a HR pixel $\hat{Y}$ as a weighted sum of the LR pixel Y and the interpolation coefficient α. The structure of $\hat{Y}$, Y and α is shown in Fig. 1.
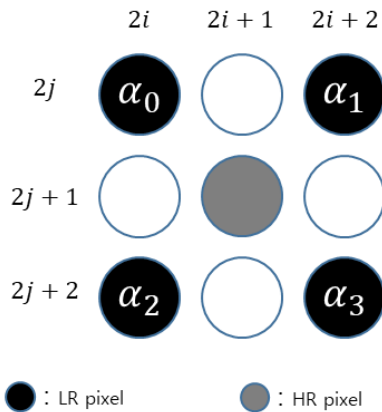

Fig. 1. The structure of LR pixel, interpolation coefficients and HR pixel.

The α is obtained by using the structural information of the pixels in the square window as shown in Fig. 2. The window consists of LR pixels or interpolated pixels, and four adjacent pixels around each pixel in the window are utilized.
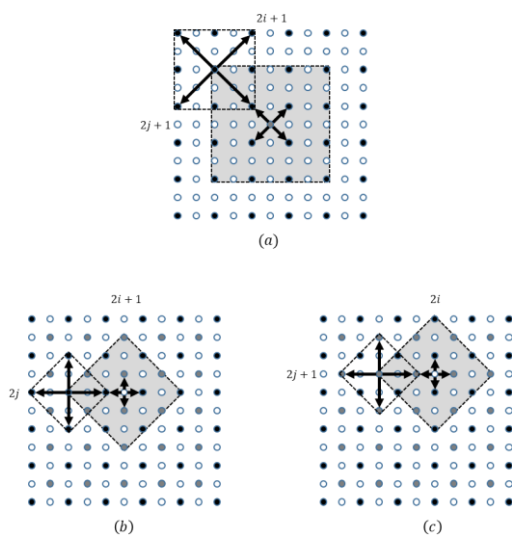

Fig. 2. The window shape used to interpolation. To interpolate for (a) $\hat{Y}_{2i+1,2j+1}$, (b) $\hat{Y}_{2i+1,2j}$, (c) $\hat{Y}_{2i,2j+1}$.

First, all $\hat{Y}_{2i+1,2j+1}$ are interpolated, and then $\hat{Y}_{2i+1,2j}$ and $\hat{Y}_{2i,2j+1}$ are interpolated. Each window which is needed to interpolate $\hat{Y}_{2i+1,2j+1}$, $\hat{Y}_{2i+1,2j}$ and $\hat{Y}_{2i,2j+1}$ is shown in Fig. 2 (a-c). Each window is used to obtain the optimal α in that window.

$$MSE_W = \|y - \alpha C\|^2 \qquad (2)$$

y in equation (2) means a set of LR pixels in Fig. 2 (a) or a set of LR pixels and interpolated pixels in Fig. 2 (b-c). C is an M² × 4 matrix, where $M(= 4)$ is the radius of window. Its elements of k-th column mean the four surrounding pixels of the k-th element of the set of LR pixels y. Thus, equation (2) represents the MSE (mean square error) between each LR pixel and the weighted sum of the four pixels around each LR pixel in the window.

$$\underset{\alpha}{argmin}\|y - \alpha C\|^2 \qquad (3)$$

Equation (3) means to find α minimizing the MSE and utilize the best structral tendency of the LR pixels in the window. The solution of equation (3) can be expressed as the following equation.

$$\alpha = (C^T C)^{-1}(C^T y) \qquad (4)$$

α is an interpolation coefficient that predicts the overall structure of the LR pixels, and it is utilized as weights in equation (1).
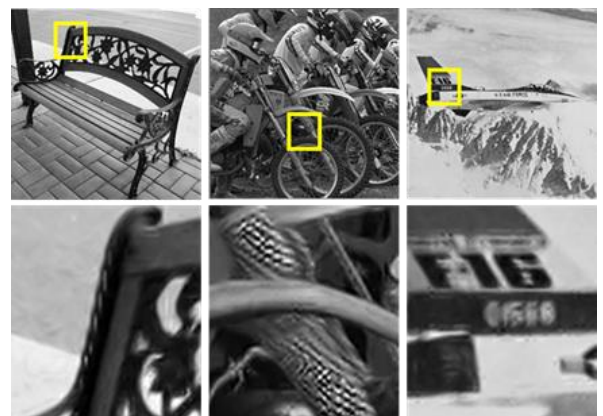

Fig. 3. Distortion artifacts example in the NEDI.

In the NEDI, distortions occur when the reference pixels contain structures that differ from the structure of the center 4 reference pixels in the window. Because the NEDI uses fixed-size window, changing the local structure of the reference pixel can have a

significant impact on calulating the interpolation coefficient. Also, since the structure of entire LR in the window is used to predict the interpolation coefficients, interpolation artifacts occur if the structures of reference pixels in the window are different from each other. Fig. 3 shows the distortion artifacts near the edge region as a disadvantage of the NEDI.

3 Proposed Algorithm

We propose two techniques to solve the problems in the NEDI. The first is recursive window extension technique. It eliminates the distortion artifact that occurs when the reference pixels in the window of the NEDI have locally different structure. The pixel that minimizes the MSE among the pixels surrounding the window is recursively included to the window for reducing the influence of the locally different structure and distortion. The second is a clipping technique [4]. It eliminates the distortion artifact caused by the reduction of the geometric duality between the LR and HR. If the window extension effect does not appear since irregular reference pixels already exist in the window, we reduce interpolation error by applying clipping technique.

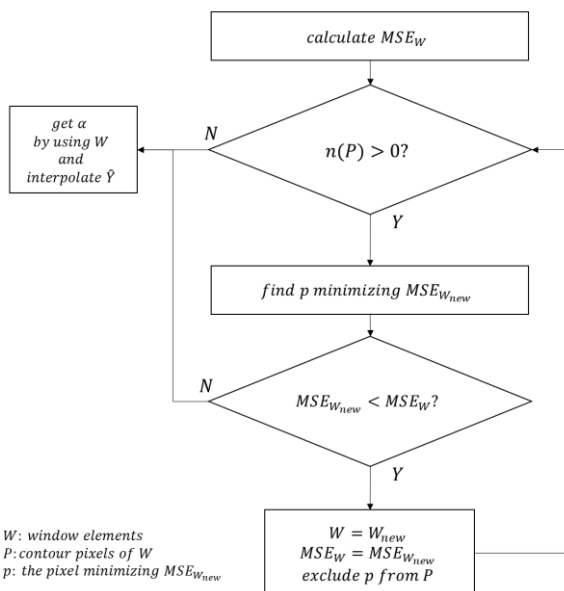### 3.1 Recursive window extension

Fig. 4. The flowchart of recursive window extension.

Fig. 4 shows the flowchart of the recursive window extension algorithm. By including pixels to the window that are similar to the overall structure of

current window, the effect of the different structures of the reference pixels within the window is reduced. The minimum MSE after including a pixel among the surrounding pixels to the window is compared with current MSE, and the pixel is included to current window only if the minimum MSE is smaller than the current MSE. If the minimum MSE is larger than the current MSE, the recursive extension process is stopped.

$$MSE_{W_{new}} = \left\| y´ - α´ C´ \right\|^2 \qquad (5)$$

Equation (5) means MSE after window extension, and it will be a criterion whether window extends or not.

Fig. 5 shows the currurent window and its nearby pixels as window extension candidates. We have repeatedly applied the inclusion of a pixel minimizing the MSE among the surrounding pixels of the current window. The reduction of the MSE means that the structural similarity of the reference pixels increases. Thus, adaptively extending the window has the effect of improving the structural similarity of the pixels. If the MSE no longer decreases, window extension is stopped, and the final interpolation coefficient α is obtained using the extended window.
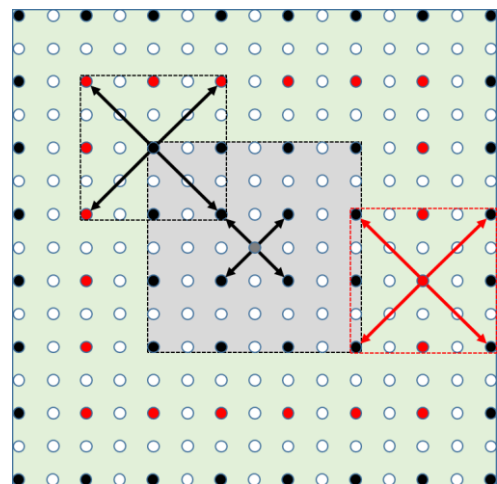

Fig. 5. Window extension candidate pixels range.

3.2 Clipping

When the structures of the reference pixels are different from each other, the geometric duality between HR and LR is reduced. Since the MSE in the window made up of irregular reference pixels is meaningless, even if the recursive window extension is applied, we need to find other interpolation method in this case. Clipping technique contribute to solving

this problem that interpolation results deviate from the surrounding four pixel values. Interpolation error can be reduced by applying the clipping technique instead of the NEDI.

$$I = \begin{cases} max(N), & if\ I > max(N) \\ min(N), & if\ I < min(N) \end{cases}$$

$$N_k \in \left\{ \begin{array}{l} the\ neighbor\ 4\ pixels\ of \\ a\ pixel\ I\ to\ be\ interpolated \end{array} \right\}$$

(6)

Equation (6) represents the clipping technique used in this paper. When the interpolated HR pixel value deviates from the surrounding four pixel values, it is replaced by the closest value among the four neighbor pixels. This reduces the distortion caused by the irregularity of the structure of the reference pixels in the window.

4 Experiment Result

We experimented with MATLAB R2017a in Intel Core i7-4770K CPU @ 3.50GHz, RAM 16.0 GB and Window 10 Pro x64 environment.

We used 47 monochrome images with a resolution of 512×512 as the original image and a down sampled image with a resolution of 256×256 as the input image. The interpolation techniques used in this experiment were bilinear, spline, bicubic interpolation, the NEDI and the proposed algorithm. The interpolation performance is compared with each other and analyzed through experiment results.
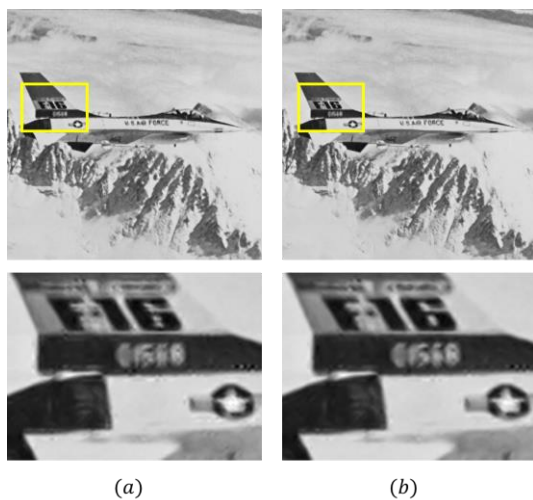

Fig. 6. The results of the (a) NEDI and (b) proposed 1.

Fig. 6 (a) shows the result of interpolation with the NEDI, and Fig. 6 (b) shows the result of proposed 1 which interpolates using recursive window extension

technique. Fig. 6 indicates that the distortion is reduced which occurred near the edge and the text in the NEDI. Fig. 7 (a) represents the result of proposed 1, and Fig. 7 (b) represents the result of proposed 2 which applys clipping technique to proposed 1. The noise occured in Fig. 7 (a) is removed in Fig. 7 (b). Fig. 8 (a) is the result of extending window by perimeter pixel set of the window, and Fig. 8 (b) is the result of pixelwise extending window. As shown Fig. 8, pixelwise window extension method represented better performance in the text area.
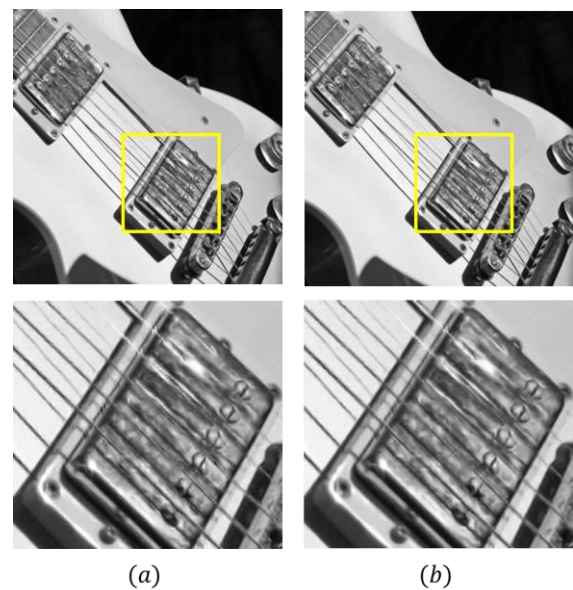

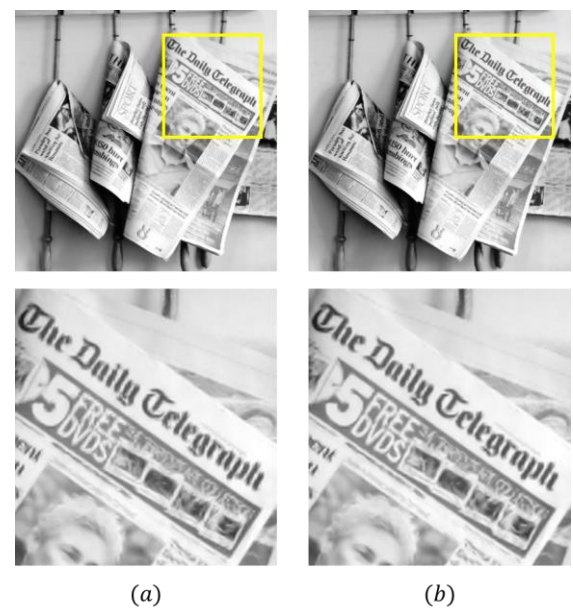Fig. 7. The results of (a) proposed1 and (b) proposed 2.

Fig. 8. The results depending on window extension methods. (a) a set of perimeter pixels, (b) pixelwise.
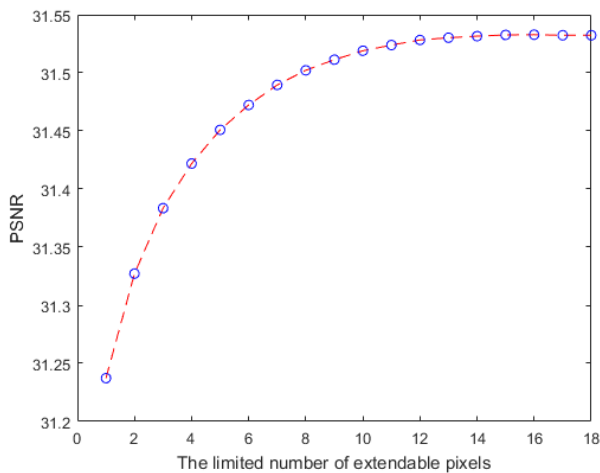
Fig. 9. The PSNR along with the limited number of

extendable pixels.

Fig. 9 shows the varying PSNR as limiting the number of extendable pixels. It can be seen that as the number of extenable pixels is increased, the PSNR increases, but the increment decreases gradually. Fig. 9 shows that it reaches a sufficient window size for performance improvement by increasing the limited number of extendable pixels.

Table 1. The comparison of the performance.

Algorithms	PSNR	EPNSR	MSSIM	Time(s)
Bilinear	31.273	24.215	0.913	0.007
Spline	31.915	25.055	0.914	0.009
Bicubic	31.935	24.851	0.917	0.005
NEDI	30.224	23.790	0.894	3.596
proposed 1	31.056	24.383	0.906	199.740
proposed 2	31.532	24.759	0.910	198.914

Table 1 compares the performance of each algorithm. The PSNR, EPSNR, and MSSIM values show that the performance of the proposed algorithms are better than that of the conventional NEDI.
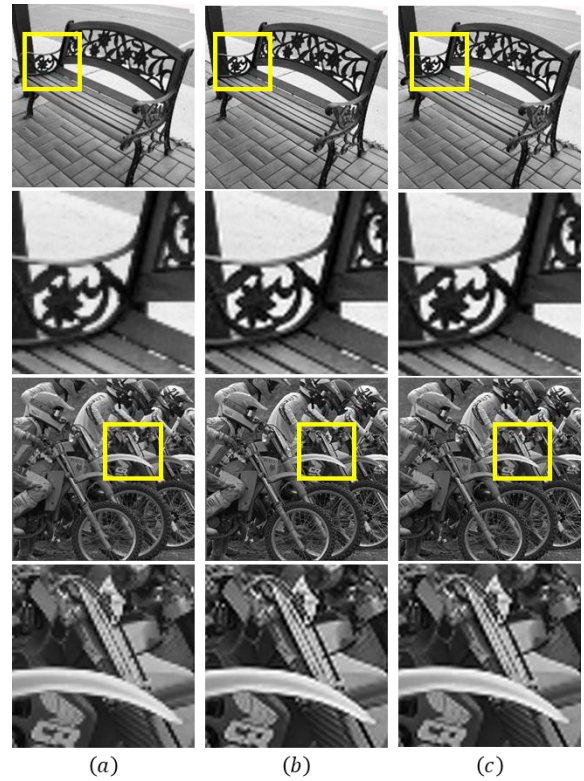

Fig. 10. The results of linear interpolations.

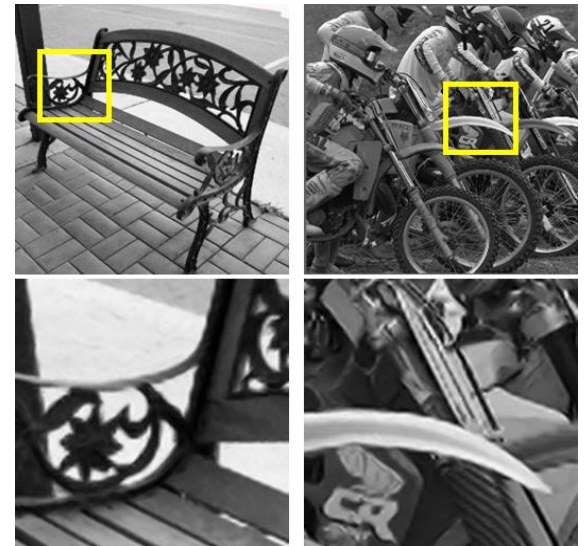(a) bilinear, (b) spline, (c) bicubic interpolation.

Fig. 11. The results of the proposed algorithm.

The proposed algorithm is not as good as the bilinear, spline, and bicubic linear interpolation methods. However, it can be seen that the subjective image quality of the algorithm shown in Fig. 10 and Fig. 11 is superior to that of the linear algorithm. In terms of implement time of the proposed algorithm,

the algorithm for adaptively extending the window increases the complexity because it determines whether to extend it in pixel units.

5 Conclusion

In this paper, we propose a recursive window extension and clipping technique. Through that, the distortion artifacts were reduced which are caused by the difference in the structure of the reference pixels and reduction of the geometric duality between the HR and LR pixels. Finally, we can confirm that the proposed algorithm shows better performance than the other conventional algorithms this paper introduced by comparing experiment results.

Acknowledgement

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