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# Super-resolution method based on edge feature for high resolution imaging

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**Abstract:** Super-resolution is recently one of the most attractive research themes. An image interpolation method using co-variance between neighboring pixels, so called New Edge-Directed Interpolation (NEDI), was proposed. It enables to interpolate pixels quantitatively regardless of edge features. However, in estimation of predictive coefficients and determination of NEDI's local window size, edge features are not made consideration. So, NEDI cannot necessarily satisfy quality of picture. In order to overcome this problem, we propose a new intra-frame super-resolution method that window sizes and configurations are adaptively determined depending on edge strengths and orientations. Experimental simulation shows that the proposed method can interpolate pixels more clearly than NEDI for many kinds of edges.

**Keywords:** Super-Resolution, Co-Variance, Bi-Linear Interpolation, Canny Edge Detection

## 1. Introduction

The technology that makes a high-resolution image from a low-resolution image, so-called "Super-Resolution", is recently one of the most attractive research themes in the field of digital image processing [1]-[4]. Super-resolution method can be separated into major two methods. One of the two uses more than two frame images to create a high-resolution image, it's so-called "multi-frame super-resolution". Another uses only one image to do that, it's so-called "intra-frame super-resolution". Then we try to create high-resolution images by the method that does not need any database and can be applied to various categories.

In this paper, we take notice of an interpolation method using co-variance between neighboring pixels and propose a new method in consideration of more edge features additionally. In the case the image includes various edges that have difference features each other, we gained better result. So, we show the validity by simulation experiment.

## 2. Background

An image interpolation method using co-variance between neighboring pixels, so called New Edge-Directed Interpolation (NEDI), was proposed [1]. NEDI enables to interpolate pixels quantitatively regardless of edge features around detected edges using relations between neighboring pixels and their co-variance. However, it uses variances in the in the step of detecting edges. Then edge features are not made consideration in estimation of predictive coefficients and determination of NEDI's local window size. So, NEDI cannot necessarily satisfy quality of image.

In order to overcome this problem, we propose a new intra-frame super-resolution method that window sizes are adaptively determined depending on edge strengths and orientations. We detect edge and its strength in an image, and set NEDI's applicable area and local window size depending on the detected edge strength. Then it enables to interpolate using necessary and sufficient information.

# 3. Conventional Method (NEDI)

### *3.1. Interpolation in NEDI algorithm*

In this method, when a high-resolution image X(i,j) is created from a low-resolution image Y(2i,2j), co-variance of the high-resolution image and that of the low-resolution image can be approximated. Then predictive pixels are estimated from co-variance of the low-resolution image. We show a predictive pixel and relation between neighboring pixels as in Fig.1. NEDI follows two steps. At the 1st step, the black dot is interpolated in Fig.1. Then the white dots are pixels of the low-resolution image.

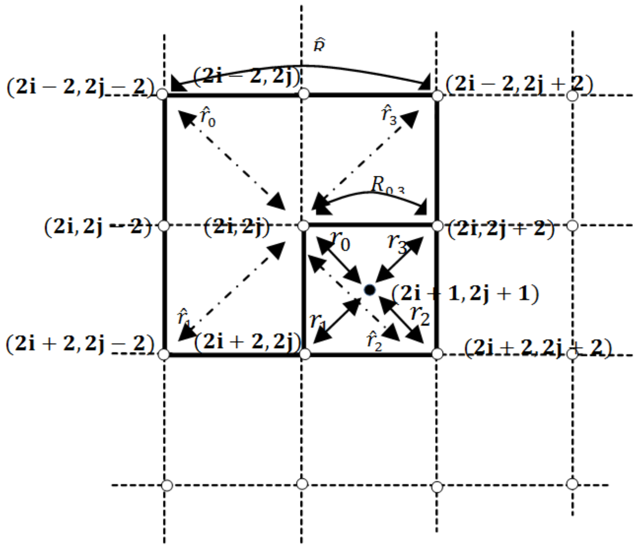



***Figure 1.*** *Geometric duality (1st step)*

First, a low-resolution image X(i,j) is separated into edge area and other area. A target pixel is regarded as a part of edge if the variance calculated from the target pixel and its neighboring four pixels is higher than the threshold have been set. Then the variances are given by

$$s = \sqrt{\frac{1}{4}\left(\begin{array}{c}(x_{i-1,j} - x_{i,j})^2 + (x_{i,j-1} - x_{i,j})^2 \\ +(x_{i,j+1} - x_{i,j})^2 + (x_{i+1,j} - x_{i,j})^2\end{array}\right)} \quad (1)$$

where x(a,b) is brightness at (a,b). In the area regarded as a part of edge, we interpolate the pixel Y(2i+1,2j+1) as following

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

where α is a1×4matrix how weight four neighboring pixels to interpolate. Then matrix α is estimated using co-variance of high-resolution image as following.

$$\vec{\alpha} = R^{-1}\vec{r} \quad (3)$$

Using brightness of low-resolution image pixels, co-variance of low-resolution image $\hat{R}, \hat{r}$ is given by

$$\hat{R} = \frac{1}{M^2}C^TC \quad , \quad \hat{r} = \frac{1}{M^2}C^T\vec{y} \quad (4)$$

where $\vec{y} = [y_1 \dots y_k \dots y_{M^2}]^T$ is the data vector containing the M×M pixels inside the local window and C is a $4 \times M^2$ data matrix whose k-th column vector is the four nearest neighbors of $y_k$ along the diagonal direction. According to (3) and (4), there is

$$\vec{\alpha} = (C^TC)^{-1}(C^T\vec{y}) \quad (5)$$

Therefore, the interpolated value of $Y_{2i+1,2j+1}$ can be obtained by substituting (5) into (2).

At the 2nd step, we use pixels interpolated at the 1st step to interpolate remaining pixels just like 1st step interpolation.

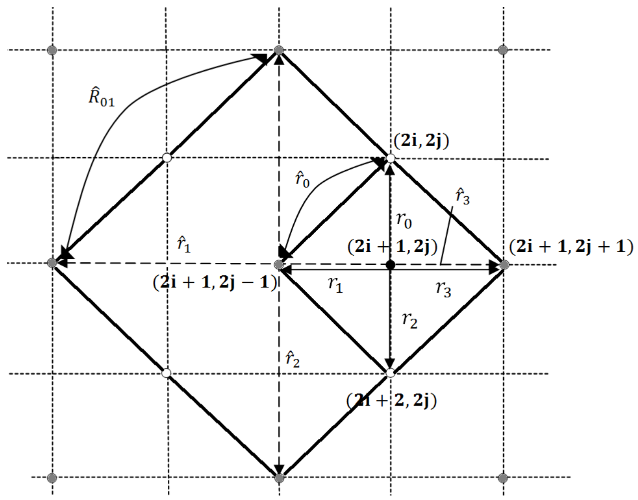
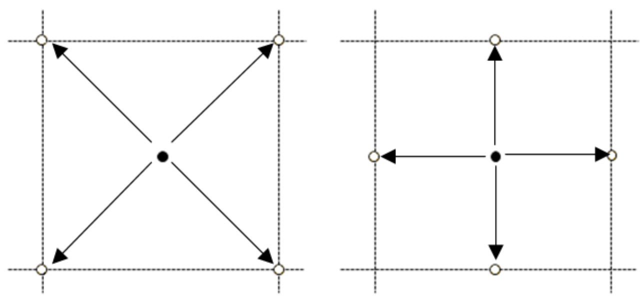



***Figure 2.*** *Geometric duality (2nd step)*

In Fig.2, the black dot is interpolated at the 2nd step, and the gray dots were interpolated at the 1st step.

In the area that was not regarded as edges, all element of predictive coefficient α are substituted 1/4, so we use simply bilinear interpolation with diagonal four pixels at the 1st step, and with horizontal and vertical pixels at the 2nd step (refer to Fig.3).



(a) 1st step (b) 2nd step

***Figure 3.*** *Direction of bilinear interpolation*

### *3.2. Interpolation Results and Its problem*

NEDI interpolates using only one local window size for whole of an image without consideration for edge features. Then, if the image includes various edges, NEDI cannot necessarily satisfy quality of picture.The case that is using information of needless pixels or is not using that of need pixels to interpolate can be thought.

We show the images interpolated using two different thresholds in Fig.4.


(a) Threshold=4


(b)Threshold=10

***Figure 4.*** *NEDI using different thresholds*

In Fig.4 (a), the parts of numbers are more clearly than that of (2), but in the parts of other gradual edges, some noises can be shown in (a) and that of (b) are interpolated more smoothly.

Besides, NEDI uses variance with four diagonal neighboring pixels to detect edges. Then it can be thought that noises of low-resolution image are detected as edges or weak edge such that we can not detect are detected (refer to Fig.5). So, noises and distortions may be inserted to interpolation pixels.

(a) Source image

(b) Detected edges

***Figure 5.*** *Edge detection using variance*

White dots in Fig.5 (b) are detected pixels as edges. It shows that not only clear edge but also flat part such a gradational part are detected as edges. If we apply NEDI to all detected pixels, it causes not only interpolation errors but also to waste processing time. These errors appear as black dots (refer to Fig.6) because delta between neighboring pixels is small and predictive coefficient is not estimated correctly.

Especially, when threshold is set small (ex. 4 or 6), many errors appear because then variance is small too and weak edges are detected. And calculation including inverse matrix ((3) and (5)) is not always done correctly.

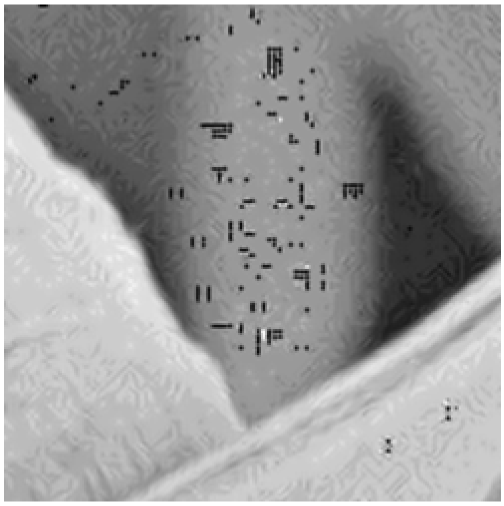


***Figure 6.*** *Interpolation errors*

# 4. Proposed Method

### *4.1. Edge Features Based Interpolation Algorithm*

We interpolate pixels using necessary and sufficient information depending on edge features. It enables to interpolate more precision than NEDI.

First, we use canny algorithm to detect edges. So, it is nearer to human sense than the method using variance (refer to Fig.7)

*Figure 7. Detected edges using canny*

We adjust thresholds of canny, and gain strengths of edges. Then we adjust local window size of NEDI depending on detected strengths. If that is strong, we set window size narrow, and if that is weak, we set window size wide. Additionally if that strength is strong, we apply the interpolation method using co-variance narrow, too. The opposite is equally true (refer to Fig.8).

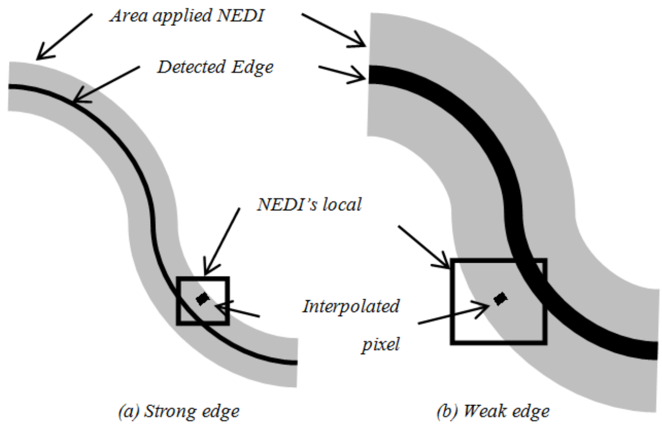



*Figure 8. Schematic of proposed method*

It enables to predict pixels matching up to each edge features. Furthermore, we can shorten processing time because area using co-variance based interpolation is much narrower than that of original NEDI.

Interpolation error is much smaller than NEDI because the area using co-variance based interpolation is limited near edges, so proposed method do not use co-variance based interpolation at flat part of image. But, if interpolation error is shown, we use bilinear interpolation at that pixel.

## 5. Experimental Results

We show validation through following simulation experiment. Source image is Lena. We use Open Source Library of computer vision, i.e, OpenCV, in patches of the program. An execution screen example is shown in Fig.9.

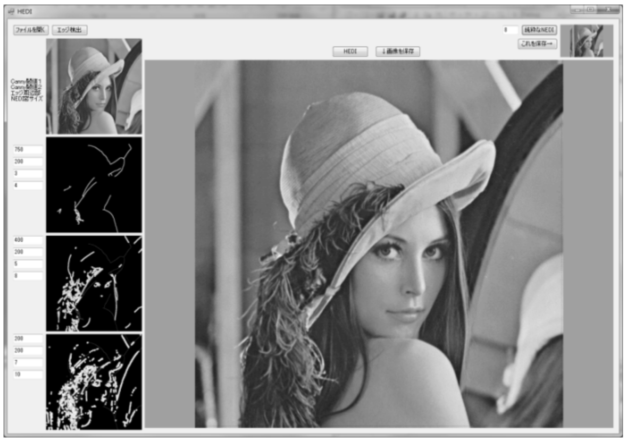


*Figure 9.Execution screen*

There is a source image, detected edges, and area applied co-variance based interpolation on the left side, reconstructed image at the center, and original NEDI image to compare with proposed one on the upper right. Gray lines are detected edges, and white area around them is applied co-variance based interpolation. The larger one is shown Fig.10.

(a) Threshold=750

(b) Threshold=400

(c) Threshold=200

***Figure 10.*** *Edge strength and area applied co-variance based interpolation*

The two reconstructed images by NEDI and proposed method are shown in Fig.11. These images ware zoomed a part of reconstructed images.

(a) NEDI

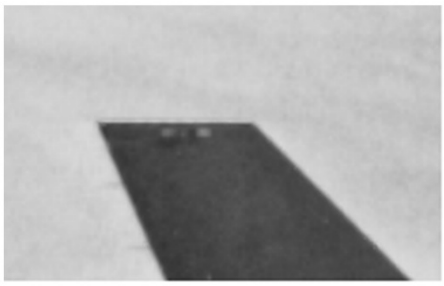
(b) Proposed method

***Figure 11.*** *Reconstructed images*

The proposed method uses small window size near strong edges, and includes fewer noises there. On the other hand, the proposed method interpolates more naturally at flat part, because NEDI detected as edges there and interpolate using co-variance but the proposed method uses bilinear interpolation. At flat area such that brightness is turning gradationally, bilinear interpolation can reconstruct more clearly than co-variance based method

Fig.12 shows the interpolated images using another image. This image includes a pretty strength edge, such around the area between the jet plane and the background. The (a) and (b)are the source image, the interpolated image by the proposed method, respectively. These experimental results also shows that the interpolated pixels around the edge, that is, the vertical tail of the jet plane surrounded with the rectangle, has a pretty sharpness compared to NEDI.

(a) Proposed method



(b) Proposed method

***Figure 12.*** *Interpolated Image for Jet Plane image*

## 4. Conclusion

In this paper, we proposed an intra-frame super-resolution method making consideration of edge features. We detected own edge strength, adjusted parameters depending on that features, and interpolate pixels using these parameters. As the result of simulation experiments, validity of proposed method was shown. This time we set thresholds and adjusted parameters manually. We are going to automate setting interpolation parameters and modify interpolation in non-edge area..

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