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Local Gradient와 Median Filter에 근거한 초해상도 이미지 재구성

(Super Resolution Image Reconstruction based on Local Gradient and Median Filter)

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요 약

본 논문은 높은 품질 SR 이미지를 획득하기 위해 국소 그라디언트를 기반으로 적응형 보간법을 이용하는 SR 방법을 제공한다. 이 방법에서, 내삽 화소와 인접하는 유효한 화소 사이에 거리는 국소 그라디언트 특징을 이용하여 고려되며, 보간 계수는 LR 이미지의 국소 그라디언트를 고려한다. 픽셀의 국소 그라디언트는 더 작을수록, 그리고 메디안 필터는 보간된 HR 이미지의 블러링과 노이즈를 감소시키기 위해 적용된다. 실험 결과는 특히 이미지의 에지 부분에서, 다른 방법과 비교하여 제안된 방법의 유효성을 보여준다.

Abstract

This paper presents a SR method using adaptive interpolation based on local gradient features to obtain a high quality SR image. In this method, the distance between the interpolated pixel and the neighboring valid pixel is considered by using local gradient properties. The interpolation coefficients take the local gradient of the LR images into account. The smaller the local gradient of a pixel is, the more influence it should have on the interpolated pixel. And the median filter is finally applied to reduce the blurring and noise of the interpolated HR image. Experiment results show the effectiveness of the proposed method in comparison with other methods, especially in the edge areas of the images.

Keywords : Super Resolution, interpolation, local gradient, median filter

I. Introduction

Super Resolution(SR) processing is to reconstruct a high resolution (HR) image from one or more low resolution (LR) input images of the same scene. SR images can offer more details that may be critical in various applications such as surveillance systems, medical imaging, satellite images, etc. Some surveys [1~3] discuss the advances and challenges on this work. Therefore, the study in this field is still an active area of research. The concept of SR from multiple frames was introduced firstly by Tsai and Huang[4] in 1984. Since then, a wide range of different approaches have been proposed. There are two

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categories of algorithms in SR reconstruction. These are learning-based methods and reconstruction-based methods. Learning-based methods first learn finer details (high frequency components) of images in the large training set that corresponds to different image regions at LR images, and then combine the high frequency details and LR images to obtain a HR image. Reconstruction-based algorithm can be classified into iterative algorithm such as Maximum a Posteriori (MAP)[5], Projection onto Convex Sets (POCS)[6~8] and non-iterative algorithm, like non-uniform interpolation[9]. Many non-iterative algorithms are used in single image interpolation such as pixel replication, bilinear interpolation, cubic-spline interpolation[10], etc. A problem with these interpolation methods is that the visual results have unacceptable effects like blurring, aliasing, or blocking.

In this paper, our primary concern is to propose a SR method for image reconstruction based on local gradient features and median filter. This method not only considers the distance between the interpolated pixel and the neighboring valid pixels but also takes the local gradient of LR images into account. The basic idea of the local gradient-based adaptive interpolation is that the value of interpolated pixel is influenced by the local gradient value of a pixel, especially in the edge areas of the image.

The rest of this paper is organized as follows: Section Ⅱ presents some background information. In section Ⅲ, our proposed algorithm is presented. The experimental results are given in section Ⅳ, and section Ⅴ states the conclusion of our paper.

Ⅱ. Background

1. Observation Model

The observation model used in SR image reconstruction contains the relation between the HR pixels and observed LR pixels. Each LR image is modeled as a noisy, uniformly down-sampled version of the HR image which has been shifted and blurred. Given p LR images Y_1, Y_2, ..., Y_p, the imaging process of Y_k from the HR image X can be formulated by:

$$Y_k = D_k B_k F_k X + N_k \quad 1 \le \mathrm{k} \le \mathrm{p} \tag{1}$$

where p is the number of available LR images, Y_k is an Nx1 vector representing the k^{th} mxn ($N = mn$ pixels) LR image in lexicographic order. If l is the resolution enhancement factor in each direction, X is a l^2Nx1 vector representing the lmx ln HR image in lexicographic order, F_k is an l^2Nx l^2N shift matrix that represents the relative motions between image k and a reference image, B_k is a blur matrix of size l^2Nxl^2N, D_k is the Nxl^2N uniform down-sampling matrix, and N_k is the Nx1 vector representing additive noise.

Each LR image contributes the new and different information about the HR image. Combining the equations in (1), we have:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \cdots \\ Y_p \end{bmatrix} = \begin{bmatrix} D_1 B_1 F_1 \\ D_2 B_2 F_2 \\ \cdots \\ D_p B_p F_p \end{bmatrix} X + \begin{bmatrix} N_1 \\ N_2 \\ \cdots \\ N_p \end{bmatrix} \tag{2}$$

Based on the observation model, there are several major steps in SR image reconstruction: registration, warping, blurring, motion cancellation, and merging the converted LR images into a final HR image [111. Registration is the process of determining where sampled values of the LR image should be placed on the HR image, thus creating a point-to-point mapping to be used in warping. Warping is the process of converting the samples of LR images, by using the relationship determined in registration, to the HR image. This typically involves a projection from the LR image plane to the HR plane, and interpolation of the LR sample values to the HR resolution. The images are processed to remove blur and noise. Finally the warped, processed LR images are merged to form the HR image.

2. Adaptive interpolation using gradient features

Image interpolation is commonly performed by some methods such as nearest interpolation, bilinear interpolation, bicubic interpolation, etc. The visual results of these interpolation methods all suffer from unacceptable effects (e.g. blurring, aliasing, blockiness) to some extent, especially in the edge of the image. In SR image reconstruction, interpolation is also the very important phase. Because of this reason and the drawback of the former interpolation methods, the adaptive interpolation is developed to yield better quality results.

Adaptive interpolation means that the way the neighboring pixels affect the value of interpolated pixel using local properties. Adaptive interpolation can be reached in different methods[12]; one method is using gradient features as the local properties.

Assume that an interpolated pixel lies exactly between two pixels, one in a flat region and one on an edge. It is reasonable to expect that the interpolated pixel should resemble the pixel in the flat area more than the other pixel. In essences, the smaller the local gradient of a pixel p_i is, the more influence it should have on the interpolated pixel. Figure 1 demonstrates a one-dimensional case. Although the interpolated pixel x is closer to the original pixel p_1, it is clear that it should be closer in value to p_2 because p_1 has a higher local gradient and is evidently on an edge. The interpolated pixels depend on both the distance between them and their neighboring pixels and on the local gradients.

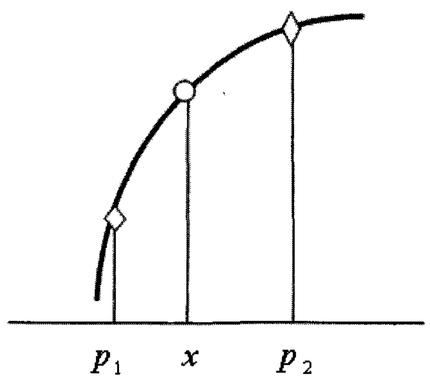


그림 1. 국소 그라디언트와 보간법
Fig. 1. Local gradient and interpolation.

Ⅲ. Proposed Algorithm

We proposed a SR method for image reconstruction using adaptive interpolation based on local gradient features and median filter. This method not only considers the distance between the interpolated pixel and the neighboring valid pixels but also takes the local gradient of LR images into account. The basic idea of the gradient-based adaptive interpolation is that the value of interpolated pixel is influenced by the local gradient value of a pixel, especially in the edge areas of the image. Actually, the smaller the local gradient of a pixel is, the more influence it should have on the interpolated pixel.

The proposed method involves three sub tasks as follows:

In the registration phase, the HR uniform grid is formed and the motion vector search is used to estimate the motions of the LR images.

In the fusion phase, the motions of the LR images are mapped onto the HR grid, and then the adaptive interpolation using local gradient features is used to calculate the interpolated pixel.

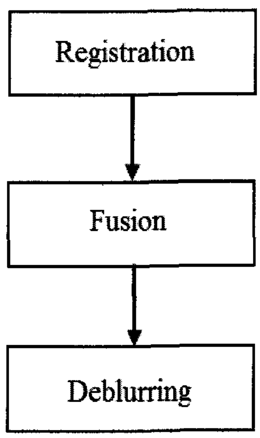


그림 2. 제안된 알고리즘의 3개의 서브 태스크
Fig. 2. Three sub tasks of the proposed algorithm.

Finally, the median filter is applied to reduce the effects of blurring and noise to form a HR image.

The details of the proposed algorithm are described as follows:

Step 1: Create the uniform grid of HR image by 2 times of LR image in each dimension.

Step 2: Take the reference LR image and place it on the uniform HR grid at the position [0, 0].

Step 3: Calculate the motion vector between the reference image and the other LR images.

Step 4: Determine the positions of other LR images on the HR grid.

Step 5: Calculate the Euclidean distance between the interpolated pixel and its neighboring pixels within the window size 2x2 on the HR grid.

Step 6: Sort the distance from the closest to the farthest and find the 3 nearest pixels around the interpolated pixel.

Step 7: Calculate the gradient value of 3 nearest pixels around the interpolated pixel.

Step 8: Determine the value of interpolated pixel based on both the Euclidean distance between the interpolated pixel and 3 nearest pixels and their gradient values.

Step 9: Apply median filter to reduce the effects of blurring and noise to obtain a HR image reconstruction.

Ⅳ. Experiment Results

The proposed algorithm was tested with standard images and real images. Given a set of LR images of the same scene with blur and noise, one LR image is chosen as a reference image. The algorithm is applied to a set of LR images to reconstruct a high quality HR image. The HR images were reconstructed by 2 times in each dimension of LR images. The following tables show the size of LR images and HR images of standard images and real images, respectively.

표 1. 실험을 위한 표준 이미지
Table 1. Standard images for experiment.

Quarter of circle	Lena
LR size: 280x276	LR size: 256x256
HR size: 560x552	HR size: 512x512

표 2. 실험을 위한 실제 영상
Table 2. Real images for experiment.

Bookshelf	Calendar
LR size: 408x306	LR size: 408x306
HR size: 816x612	HR size: 816x612

To evaluate the quality of HR image reconstruction, we will compute the peak signal to noise ratio (PSNR) of the reconstructed image. The mean squared error (MSE) of the reconstructed image is:

$$MSE = \frac{\sum |f(i,j) - f_0(i,j)|^2}{4N^2}$$

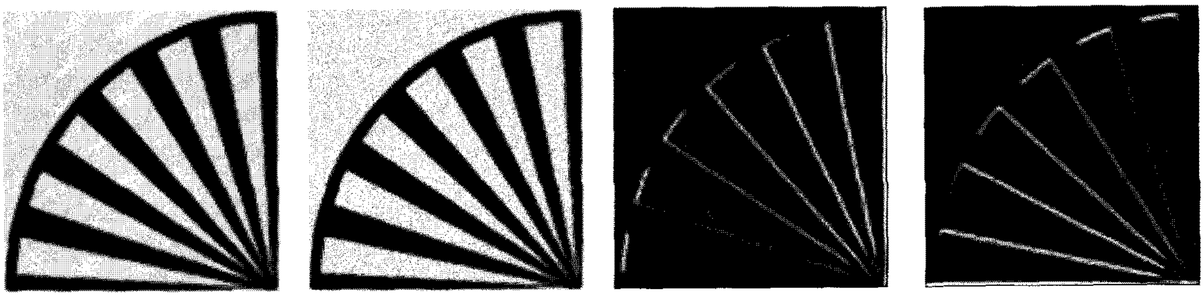
where:

$f(i,j)$: the reconstructed image
$f_0(i,j)$: the original HR image
N: size of LR image

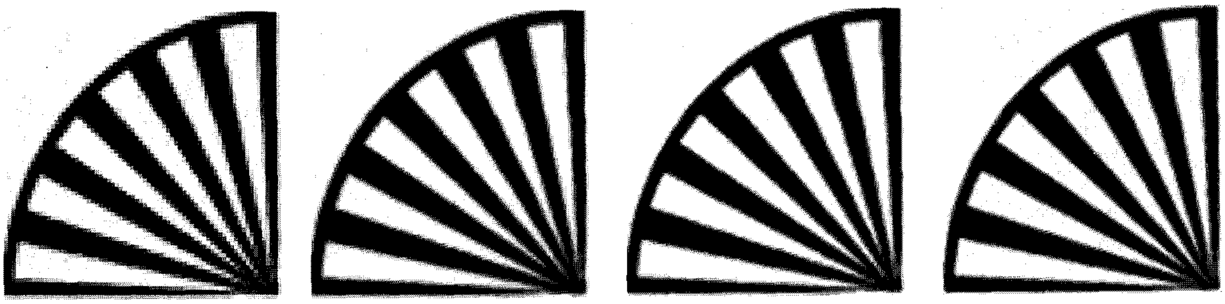
The summation is over all pixels. The root mean squared error (RMSE) will be the root of MSE. PSNR is measured by using:

$$PSNR_{dB} = 20\log_{10}\left(\frac{255}{RMSE}\right)$$

The following figures show the results of the proposed algorithm in comparison with other methods. The proposed method showed its effect to reconstruct a HR image, especially in the edge areas of the images. The proposed method has the higher PSNR than other methods.



Original image | One of LR image | Vertical gradient of LR image | Horizontal gradient of LR image



Nearest interpolation PSNR = 24.163 dB | Bilinear interpolation PSNR = 26.043 dB | Bicubic interpolation PSNR = 27.170 dB | Proposed Algorithm PSNR = 30.685 dB

그림 3. "서클의 분기" 이미지 재구성
Fig. 3. "Quarter of circle" image reconstruction.

Original image | One of LR image | Vertical gradient of LR image | Horizontal gradient of LR image

Nearest interpolation PSNR = 26.457 dB | Bilinear interpolation PSNR = 28.626 dB | Bicubic interpolation PSNR = 28.647 dB | Proposed Algorithm PSNR = 30.055 dB

그림 4. "Lena" 이미지 재구성
Fig. 4. "Lena" image reconstruction.

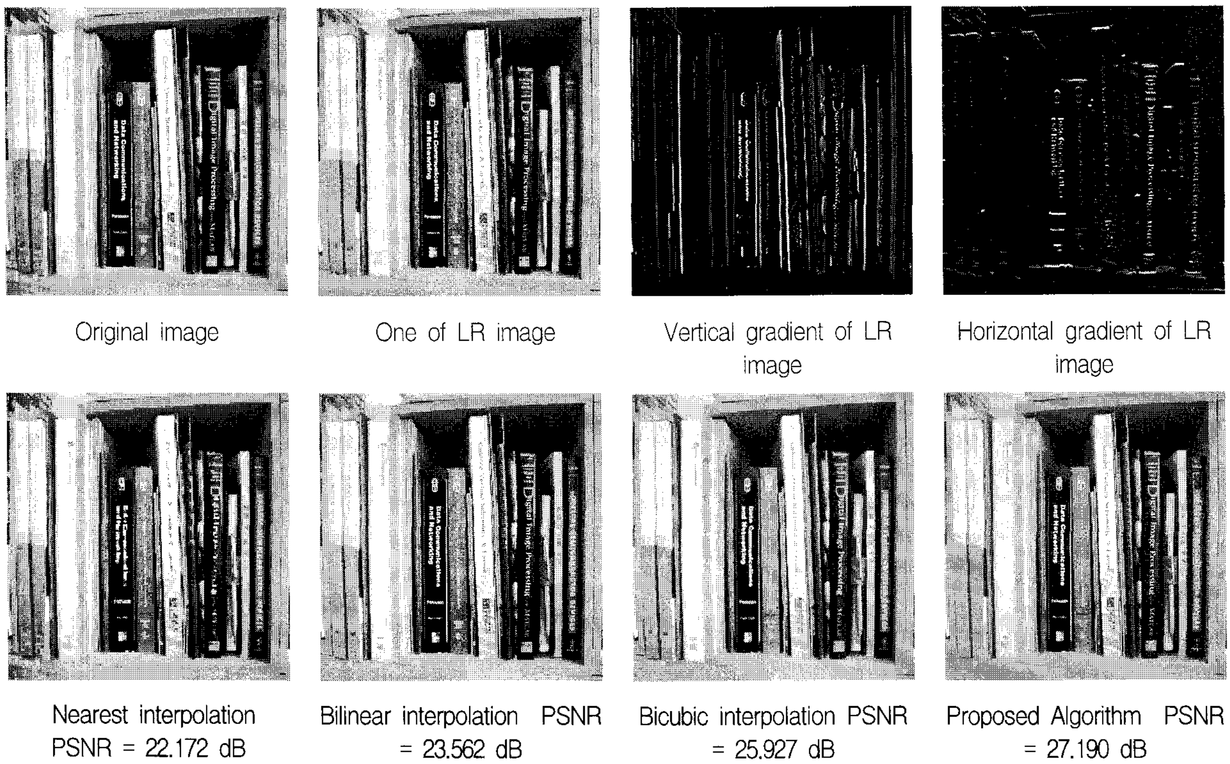


그림 5. “Bookshelf” 이미지 재구성
Fig. 5. “Bookshelf” image reconstruction.

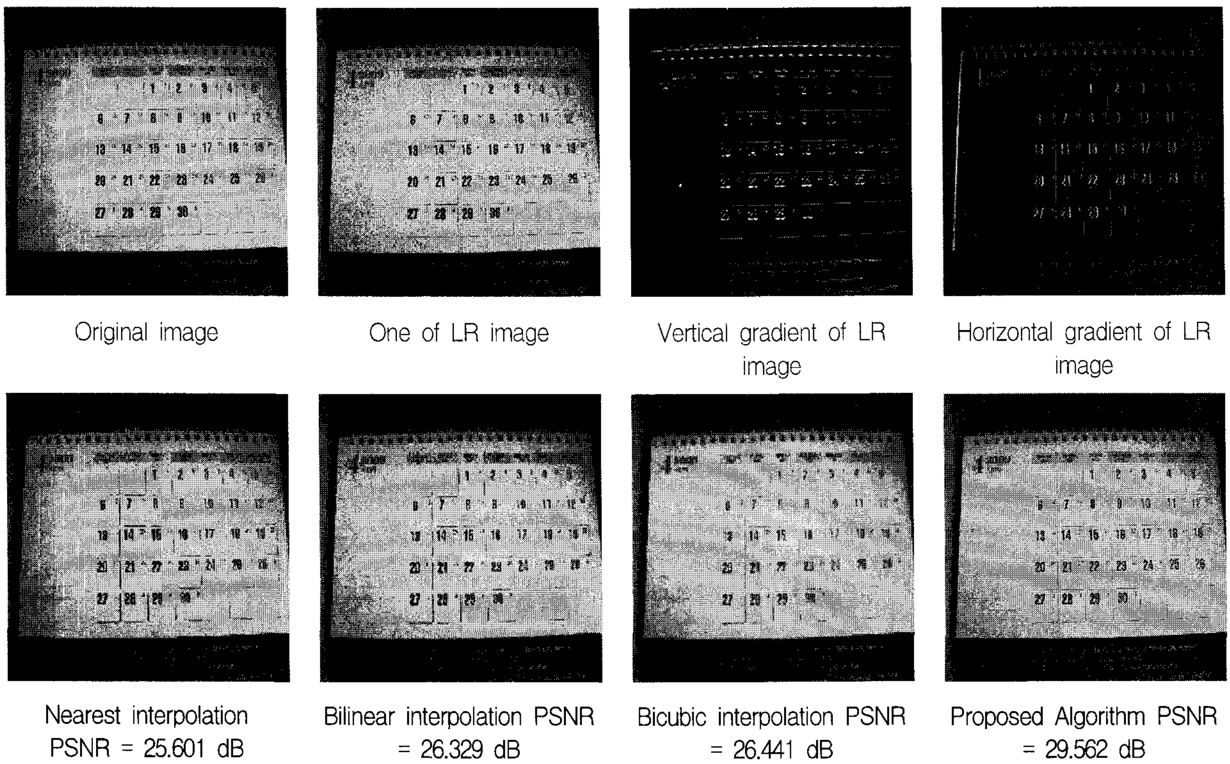


그림 6. “Calendar” 이미지 재구성
Fig. 6. “Calendar” image reconstruction.

V. Conclusions

Images with high resolution are usually desired and required in many imaging applications. As applications involving the capture of digital images become more ubiquitous - and at the same time more ambitious - there is a driving need for digital images of higher resolutions and quality. In this paper, we proposed a SR method for image reconstruction using adaptive interpolation based on local gradient features and median filter. The experiment results show that the proposed method is effective to produce a better image which both preserves edges and removes noise in comparison with other methods.

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REFERENCES

[1] S. C. Park, M. K. Park, M. G. Kang, "Super-Resolution Image Reconstruction: A Technical Overview," IEEE Signal Processing Magazine, vol. 20, no. 3, pp. 21-36, 2003.

[2] R. Marsh, T. R. Young, T. Johnson, and D. Smith, "Enhancement of Small Telescope Images Using Super-Resolution Techniques," Publications of the Astronomical Society of the Pacific, vol. 116, no. 819, pp. 477 - 481, 2004.

[3] J. D. Ouwerkerk, "Image super-resolution survey," Image and Vision Computing, vol. 24, no. 10, pp. 1039 - 1052, 2006.

[4] R. Y. Tsai, and T. S. Huang, "Multiframe image restoration and registration," Advances in Computer Vision and Image Processing, no. 1, pp. 317 - 339, 1984.

[5] M. E. Tipping, and C. M. Bishop, "Bayesian Image Super-Resolution," Proceedings of Advances in Neural Information Processing Systems, vol. 15, pp. 1303 - 1310, 2003.

[6] M. Elad, and A. Feuer, "Restoration of a single super-resolution image from several blurred, noisy, and under-sampled measured images," IEEE Transactions on Image Processing, vol. 6, pp. 1646 - 1658, 1997.

[7] H. Stark, and P. Oskoui, "High-resolution image recovery from plane-image arrays using convex projections," Journal of the Optical Society of America A, vol. 6, no. 11, 1989.

[8] A. J. Patti, M. I. Sezan, and A. M. Tekalp, "High resolution image reconstruction from a low resolution image sequence in the presence of time-varying motion blur," Proc. of the IEEE Intl. Conf. on Image Processing, vol. 1, 1994.

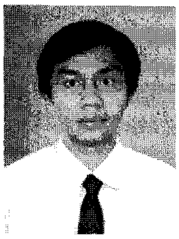
[9] M. S. Alam, J. G. Bognar, R. C. Hardie, and B. J. Yasuda, "Infrared image registration and high-resolution reconstruction using multiple translationally shifted aliased video frames," IEEE Transactions on Instrumentation and Measurement, vol. 49, no. 5, pp. 915-923, 2000.

[10] S. W. Lee and J. K. Paik, "Image interpolation using adaptive fast B-spline filtering," IEEE Intl. Conf. on Acoustics, Speech, and Signal Processing, vol. 5, pp. 177-180, 1993.

[11] T. Boult and M. Chang, "Efficient image warping and super-resolution," Proceedings of the Third Workshop on Applications of Computer Vision, pp. 56 - 61, 1996.

[12] H. C. Ting, and H. M. Hang, "Spatial adaptive interpolation of digital image using fuzzy inference," Proc. of SPIE, vol. 2727, pp. 1206 - 1217, 1996.

저 자 소 개



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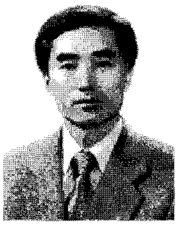

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