Maximal PSNR Wavelet Bi-linear Interpolation Iterative Algorithm in Remote Sensing Image

Liu Bo[1,2,3], Qu Youshan[1], Feng Guilan[1,3], Yang Xiufang[4], Xiangli Bin[1]

1 *Xi'an Institute of Optics and Precision Mechanics of CAS*, *Xi'an* 710068

2 *Xi'an Institute of Technology*, *Xi'an* 710032

3 *Graduate School of CAS*, *Beijing* 100039

4 *College of Machinery and Precision Instrument*, *Xi'an University of Technology*, *Xi'an* 710048

Abstract The variable relationship between the threshold of the extrapolation and its correspondent Peak of the Signal-to-Noise Ratio (PSNR) in the Wavelet Bi-linear Interpolation Algorithm is deeply analyzed. The Maximal PSNR Wavelet Bi-linear Interpolation Iterative Algorithm is proposed. This algorithm can automatically search the optimal extrapolation threshold to improve the resolution of the optical remote sensing image without damaging its original information, which makes the detail information of the processed image more favorable to be observed and analyzed. The experiment results show that the PSNR of the image reconstructed by this algorithm is 5. 5 dB and 2. 5 dB higher than that of those reconstructed by the Bi-linear Interpolation and the Wavelet Scale-Function Interpolation respectively, and its entropy is 1. 3 times of its original image. It is an effect algorithm to improve the spatial resolution and entropy of the Optical Remote Sensing Image.

Keywords Bi-linear interpolation; Wavelet transform; Spatial resolution; PSNR; Entropy

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0 Introduction

With the development of space technique and the improvement of remote sensing detect art, remote sensing has been widely applied to meteorological observing, natural disaster detecting, earth surface surveying and other many fields. Due to the visual explanation still is the most basic explanation method of these optical remote sensing images[1]. Therefore, it is required to process the original remote sensing image to be favorably observed without damaging its primary information. Thus it is hoped to use interpolation to improve the resolution and detail information of a remote sensing image for observing and analyzing.

At present, the major interpolation methods are Fractal Interpolation, Nearest Interpolation, Bi-linear Interpolation, and Bi-cubic Interpolation, and so on[2]. Using these methods directly to process an original image can amend its visual effect to some degree. But these algorithms only consider the local (not global) pixels correlation of the processed image, which improve the image visual effect on one hand and damage its original high frequency detail on another hand. The Wavelet Bi-linear Interpolation Algorithm is a current proposed approach. It is a new algorithm by combining the wavelet transform with Bi-linear Interpolation. For the wavelet transform and its inverse transform are global transform to an image, the Wavelet Bi-linear Interpolation overcomes the shortcoming which purely using an interpolation method to process remote sensing images can distort their local information, while the threshold of the extrapolation in the algorithm is determined by man. It is randomness and can create artificial error. In order to avoid the artificial random error, the relationship between the PSNR and the threshold of extrapolation in Wavelet Bi-linear Interpolation Algorithm is analyzed in detail and the maximal PSNR Wavelet Bi-linear Interpolation is established in this paper, which can automatically search the optimal high-resolution image with a maximal PSNR.

1 Wavelet Bi-linear interpolation

An image can be decomposed to horizontal, vertical and diagonal high frequency images and a low frequency image by wavelet transform. There exists similarity between the high frequency images at the same direction. This similarity is used in the Wavelet Bi-linear Interpolation Algorithm to enhance the high frequency information of an image.

The procedure of the decomposition of an image by wavelet transform is as follows[3~6]:

Tel: 029- 83208971 Email: liubu0721@163. com

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Suppose the original image is IL. Then the first decomposition of an image is

$$[IL1, IH1, IV1, ID1] = dwt2(IL) \quad (1)$$

The second decomposition of the image is

$$[IL2, IH2, IV2, ID2] = dwt2(IL1) \quad (2)$$

Where IH1 and IH2 are horizontal high frequency detail images; IV1 and IV2 are vertical high frequency detail images; ID1 and ID2 are diagonal high frequency detail images; IL1 and IL2 are low frequency images; *dwt2* denotes the 2-D Discrete Wavelet Transform.

The inverse wavelet transform is

$$IL1 = idwt2(IL2,\ IH2,\ IV2,\ ID2) \quad (3)$$

Where, the *idwt2* denotes the inverse wavelet transform.

In the same way, from the IL1, IH1, IV1, ID1, the high-resolution image IL can be reconstructed through *idwt2*.

$$IL = idwt2\ (IL1,\ IH1,\ IV1,\ ID1) \quad (4)$$

The horizontal, vertical and diagonal detail images decomposed by the wavelet transform reflected the edge feature of the original image. Due to different frequency bands of the high frequency detail images in same direction are similar. IH1, IV1 and ID1 are similar to IH2, IV2, ID2 respectively. Therefore, if any high frequency images were obtained, the higher frequency images could be estimated by similar transform. And then a higher resolution image could be reconstructed by inverse wavelet transform. Suppose the original image IL is a low-passed filtering image. The reconstructed procedure can be described as follows: first, IL is decomposed to IH1, IV1, ID1 and IL1 by wavelet transformation; second, the high frequency detail IH0, IV0, ID0 is gotten by similar transformation from IH1, IV1, ID1; third, IH, IV, ID is obtained by an appropriate threshold restriction to the IH0, IV0, ID0. Finally, a higher resolution image can be reconstructed by inverse wavelet transformation.

$$I = idwt2\ (IL,\ IH,\ IV,\ ID) \quad (5)$$

If the high frequency component is set to 0 directly, the reconstructing algorithm by inverse wavelet transformation is called as the Wavelet Scale Function Interpolation. And if the bi - linear similar transform is used to realize the similar extrapolation of its high frequency, the algorithm is called as Wavelet Bi-linear Interpolation. The wavelet transform and its inverse transform can be found in[3,4], and the bi-linear similar extrapolation interpolation can be found in[2].

2 Relationship between PSNR and the extrapolating threshold

PSNR is an objective evaluation parameter close to human vision, and it can be used to compare a reconstructed image to its original image. The formula of PSNR[1] is

$$PSNR = 10\log_{10}(255^2 \times M \times N/P) \quad (6)$$

Where, $P = \sum_{i=0}^{M-1}\sum_{j=0}^{N-1}[E(i,j) - E'(i,j)]^2$, the $E(i,j)$, $E'(i,j)$ are gray intensities of the pixel (i, j) in the original image and its reconstructed image respectively.

Different thresholds to restrict the high frequency similar extrapolation can construct different images. For example, there is an original remote sensing image of a city in Fig. 1. It is reconstructed to 256 different images by Wavelet Bi-linear Interpolation Algorithm, with step length $dt = 1$, and threshold changing from 0 to 255. The variable relationship between PSNR and their threshold is shown in Fig. 2. As shown in the variable curve, when the threshold is large than 70, the high frequency of the reconstructed image has been badly destroyed, so the PSNR is low.

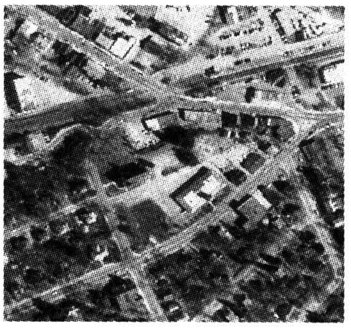

Fig. 1 A partial remote sensing image of a city

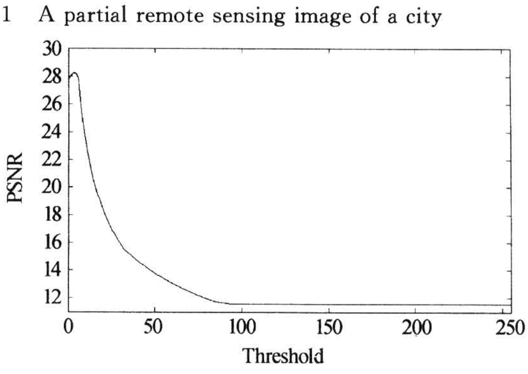

Fig. 2 Varying relationship between PSNR and the threshold

It can be seen from the curve of Fig. 2: 1) The PSNR has an absolute maximum when the threshold of the high frequency extrapolation changes from 0 to 255; 2) The PSNR is lower when the threshold is higher than the threshold relating to the maximal PSNR. This means that when the threshold of high frequency extrapolation is higher, the high frequency extrapolation destroys the original image's high frequency information. As a result, PSNR will be reduced because the image is distorted. When the threshold is larger than 71, the PSNR of the reconstructed images is close to a constant; 3) When the threshold is set to 0, namely, the three high frequency matrixes in horizontal, vertical and diagonal directions are set to zero, the Wavelet Bi-linear Interpolation degenerates into Wavelet Scale-Function Interpolation.

As shown in Fig. 2, the PSNR of an image, reconstructed by wavelet bi-linear interpolation with the threshold of high frequency extrapolation at the PSNR maximum point, is higher than that of the image reconstructed by wavelet scale-function interpolation. When the threshold is 0, the reconstructed image is shown in Fig. 3(a). The image detail information is better than its original image. When the threshold is 4, the PSNR of the reconstructed image is maximal. As shown in Fig. 3(b), detail information of the image is better than Fig. 3(a). When the threshold is in [70, 255], PSNR of the reconstructed image changes very lowly and the high frequency information of their reconstructed image has been badly destroyed by extrapolation, as shown in Fig. 3(c), (d). These images have been badly distorted.

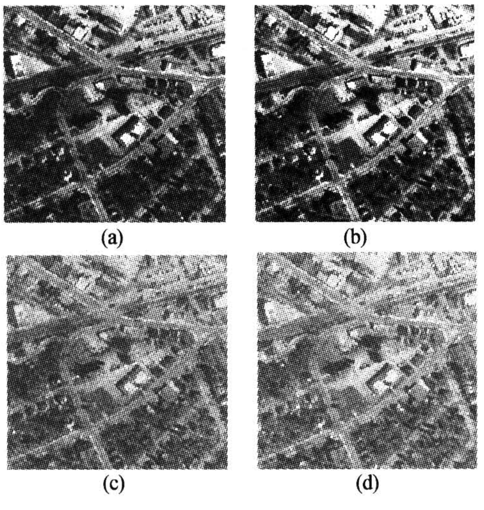

Fig. 3 The reconstructing result of wavelet Bi-linear interpolation with threshold 0, 4, 70, 255 respectively

According to many times test and application in practical, there exists the similar curve shown in Fig. 2, that is, when the threshold of the high frequency extrapolation changes from 0 to image pixel's saturated value, PSNR firstly increases and reaches a maximum, then decreases to an invariable small constant. More experiments prove that there are some optical remote sensing images whose reconstructed images' PSNR curve may exist relative maximum. In order to found out an image with an absolute maximum of PSNR, the searching scope will cover the whole interval [0, 255]. Thus the following Wavelet Bi-linear Interpolation Iterative Algorithm is established.

3 Wavelet Bi-linear interpolation iterative algorithm

Suppose an original optical remote sensing image is IL, the threshold of high frequency extrapolation is T, the initial value of T is $T_0=0$, the step length of the threshold is dt (usually $dt=1$), the initial value of PSNR is PSNR0 = 0, and the reconstructed high-resolution image is I, then the Wavelet Bi-linear Interpolation Iterative Algorithm who can improve the space resolution of optical remote sensing images is as follows:

Step1: decompose an original optical remote sensing image IL by Wavelet Transform, that is

[IL1, IH1, IV1, ID1] = $dwt2$(IL)

Step2: calculate the extrapolation matrix IH1, IV1, ID1 by using Bi-linear Interpolation Algorithm to IH0, IV0, ID0 respectively.

Step3: using the threshold $T=T_0+dt$ limits IH0, IV0, ID0 to obtain IH, IV, ID.

Step4: use inverse wavelet transform to get a candidate of the high-resolution image, that is, I = $idwt2$ (IL, IH, IV, ID).

Step5: calculate PSNR by formula (6).

Step6: compare PSNR to PSNR0:

if PSNR > PSNR0, then

$T=T_0$, $I=I_0$, RSNR0 = PSNR.

If $T=255$ then stop calculating.

else Return to step3.

else

if $T=255$ then Stop calculating.

else Return to step3.

Step7: The maximum of PSNR: PSNR = PSNR0, the optimal high-resolution image $I=I_0$, the best threshold $T=T_0$.

Through the previous algorithm processing, a high-resolution image with a maximal PSNR can be reconstructed.

4 Experiment

In order to prove the ability of Wavelet Bi-linear Interpolation Iterative Algorithm to improve the spatial resolution of optical remote sensing images and evaluate it objectively, the information entropy is used to be another norm to evaluate the reconstructed high-resolution images. The experiments are as following:

Experiment 1: The part of testpatl image was chosen as an original image. In order to compare the processing effect, processed results of Bi-linear Interpolation, Wavelet Scale-Function Interpolation and Wavelet Bi-linear Interpolation Iterative Algorithm were compared. The image and its reconstructed images are shown in Fig. 4.

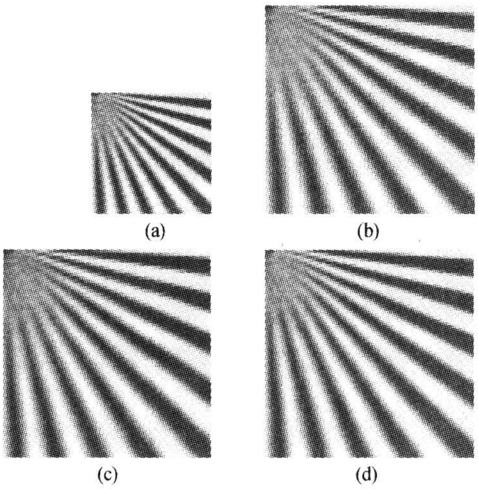

Fig. 4 The experiment result of testpatl: (a) original image; (b), (c), (d) are the reconstructed results of Bi-linear Interpolation, Scale function Interpolation, and Wavelet Bi-linear Interpolation Iterative Algorithm

The PSNR and entropy of these images are given out in table 1. The PSNR of Wavelet Bi-linear Interpolation Iterative Algorithm is 4. 4 dB and 1. 3 dB higher than that of those reconstructed by Bi-linear Interpolation and Wavelet Scale-Function Interpolation respectively. The entropy of original image is 11. 9254 bit, and the entropys of images reconstructed by Bi-linear Interpolation, Wavelet Scale-Function Interpolation and Wavelet Bi-linear Interpolation Iterative Algorithm are 13. 6431 bit, 13. 6667 bit and 13. 7556 bit respectively. The proposed novel algorithm not only improves the PSNR effectively, but also increases entropy of the image and optimizes the image detail information.

Tab. 1 The results of the experiment 1

Interpolation method	PSNR	Entropy
Bi-linear Interpolation	24. 14 dB	13. 64bit
Wavelet Bi-linear Interpolation	27. 21 dB	13. 67bit
Wavelet Bi-linear Interpolation Iterative Algorithm	28. 52 dB	13. 76bit

Experiment 2: A part of the optical remote sensing image of a city was chosen as the original testing image. The image and its reconstructed images are shown in Fig. 5. The PSNR and entropy of this experiment is shown in table 2.

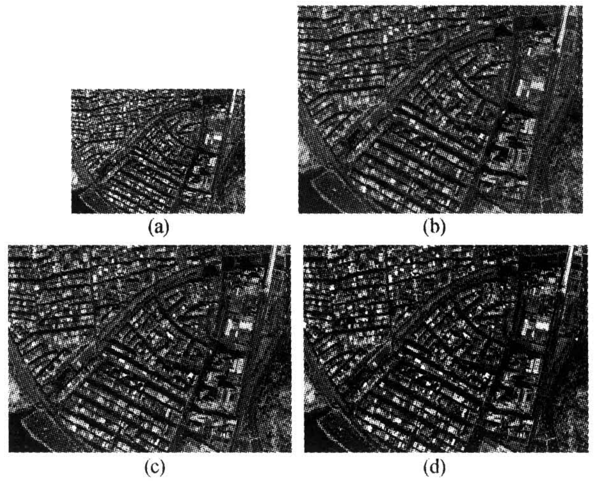

Fig. 5 Experiment 2: (a) Original remote sensing image of Taipei City; (b), (c), (d) are the reconstructed results of Bi-linear Interpolation, Scale-Function Interpolation, and Wavelet Bi-linear Interpolation Iterative Algorithm

Tab. 2 The results of the experiment 2

Interpolation method	PSNR	Entropy
Bi-linear Interpolation	24. 19 dB	20. 54bit
Wavelet Bi-linear Interpolation	27. 16 dB	20. 55bit
Wavelet Bi-linear Interpolation Iterative Algorithm	29. 55 dB	20. 56bit

As shown in table 2, the PSNR of the image reconstructed by Wavelet Bi-linear Interpolation Iterative Algorithm is 5. 5dB and 2. 5 dB higher than that of images reconstructed by Bi-linear Interpolation and Wavelet Scale-Function Interpolation respectively. The entropy of the initial image is 18. 278 bit, and the entropy of the reconstructed images is 20. 5457 bit, 20. 5469 bit and 20. 6132 bit respectively.

From the Fig. 4 and Fig. 5, although Bi-linear Interpolation and Wavelet Scale-Function can improve spatial resolution of an image, but its the high frequency detail of the images can' t be amended for there exist stripes, square effect and ladder-like edges. Therefore, the entropy and PSNR of these reconstructed images are lower (In Table 1 and 2). The Wavelet Bi-linear Interpolation Iterative Algorithm can automatically find out the image, with maximal PSNR, larger entropy, and better detail information. The vision effect of the images is obviously improved.

5 Conclusion

The two experiments results prove that the proposed Maximal PSNR Wavelet Bi-linear Interpolation Iterative Algorithm applied to the reconstruction of the optical remote sensing images can not only improve their spatial resolution and PSNR, but also can amend their high frequency information and increase their entropy. The processed images have more rich and clear detail information, and they are more favorable to be observed by eye. This proves that the Wavelet Bi-linear Interpolation Iterative Algorithm is an effective approach to enhance the spatial resolution of an optical remote sensing image.

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小波双线性插值迭代算法应用于光学遥感图像

刘 卜[1,2,3] 屈有山[1] 冯桂兰[1,3] 杨秀芳[4] 相里斌[1]

(1 中国科学院西安光学精密机械研究所,西安 710068)

(2 西安工业学院,西安 710032)

(3 中国科学院研究生院,北京 100039)

(4 西安理工大学机械与精密仪器工程学院,西安 710048)

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摘 要 分析了小波双线性插值中高频外推阈值门限与重建图像峰值信噪比的变化关系,提出了峰值信噪比最大小波双线性插值迭代算法.提出的算法能够自动搜索到峰值信噪比最大的高频外推最佳阈值门限,实现了在不破坏光学遥感图像原始信息的情况下,提高图像的空间分辨率,有利于对图像的细节信息进行观察分析.实验结果表明,该算法重建图像的峰值信噪比比双线性插值和全小波插值重建图像的峰值信噪比高5.5 dB和2.5 dB,重建图像的熵增加到原图像的1.3倍.

关键词 双线性插值;小波变换;空间分辨率;峰值信噪比;熵

Liu Bo was born in 1964. He received his B. S degree in physics from Beijing University in 1985 and received his M. S degree in plasma body from Beijing Institute of Applied Physics and Computational Mathematics in 1990. Now he is an Associate Professor in Xi′an Institute of Technology, and a Doctor candidate in the Laboratory of Space Optics, Xi′an Institute of Optics and Precision Mechanics, CAS. His research interests include space optics, image processing and target recognition.