SATELLITE IMAGE ENHANCEMENT TECHNIQUE BASED ON LANCZOS INTERPOLATION AND NLFMT FILTERING

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ABSTRACT

Satellite images are being used nowadays in various fields such as weather forecasting, remote sensing, cartography, oceanography etc. Obtaining high quality images are of prime importance in such cases. But it may not be always possible due to sensor limitations, atmospheric conditions and due to transmission. Thus the images suffer from the drawback of losing high frequency contents (which results in blurring). A wavelet domain approach based on method noise thresholding and non local means (NLM) is proposed for the enhancement of the images. An input image is passed through a NLM filter, then its method noise is thresholded. The NLM filtered image is summed with the thresholded method noise to cater for the image details removed by the NLM filter. The denoised image is interpolated using the Lanczos interpolator for resolution enhancement. Objective and subjective analyses reveal superiority of the proposed technique over the conventional and state-of-the-art image enhancement techniques.

Keywords: Non-Local-Means, wavelet transform, Lanczos interpolation, resolution enhancement (RE).

INTRODUCTION

In this paper, we propose a modified lanczos interpolation technique for the resolution enhancement of images. It provides a smooth interpolant and is more accurate than other interpolation methods. Since satellite images are normally affected by random noise, non-local means filtering is used to suppress the noise. The performance of the proposed algorithm is evaluated using PSNR (Peak Signal to Noise Ratio) and Image Quality Index.

The captured images are always contaminated by noise, caused during image acquisition or transmission. Hence the image quality is degraded heavily. So we are in need of estimating the noise signals in order to denoise the images. During the process of noise removal, we should adopt a trade-off between the actual noise being removed and the actual image features. The general method of denoising is to use a low pass filter, which will remove the noise along with the high frequency image components, which produces overly smoothed denoised images.

Most of the denoising methods¹-² use a model for differentiating the noise from the original signal based on the following observations: (i) the noise and original signal have different behavior in multi resolution representation (ii) the significant image features such as edges over-exceed noise information especially at low resolutions¹³. Hence the wavelet transform is used for the purpose of image denoising because of its multi resolution and energy compaction properties. The two mostly used wavelet thresholding methods used for image denoising are hard thresholding and soft thresholding. In the case of hard thresholding, the coefficients are left unchanged if their values are greater than a given threshold but in soft thresholding, it shrinks the wavelet coefficients to zero by the threshold value ard thresholding, but it produces better results. The soft thresholding induces more error than the hard thresholding method. These methods are very efficient if the coefficients of the underlying signal are known in advance.

Recently, Buades et al. proposed a Non Local-means (NL-means) filter¹⁴ which systematically uses all the possible self-similarity the image can provide and similarity of local patches to determine the pixel weights. As the patch size reduces to one pixel, the NL means filter becomes equivalent to the Bilateral Filter. The former better cleans the edges without losing too many fine structures and details while the later loses details and creates irregularities on the edges. Further, Kervrann et al.¹⁵ extended the work of⁴ by controlling the neighborhood of each pixel adaptively. All these denoising methods works well with less noise (high SNR) but fails to do so with more noise (low SNR). As both the target pixel and the similar local patches which are used to
find the pixel weights are noisy, the estimate of NL-means filter becomes biased. To cater for this problem of noisy target pixel, adaption of central kernel weight (AKW) to the degree of noise is proposed. But this does not take care of the similar noisy local patches and hence, especially at higher noise, the biased estimate degrades or blurs the image by removing much of the image details. In order to resolve these issues, an amalgamation of NL means filtering and its method noise thresholding using wavelets has been proposed for image denoising.

The rest of the paper is organized as follows: In section II, the proposed method for resolution enhancement and image denoising are presented. Experimental results and performance comparison are discussed in section III. Finally, conclusions are presented in section IV.

**PROPOSED METHOD**

In this paper, we propose a method for the enhancement of images using Lanczos interpolation. NLM filtering is done to remove the noise present in the satellite images. Apply lanczos interpolation on filtered image to obtain a high resolution image. The flow chart of the proposed method is shown in fig.1.

**Non-local Means Filter**

The Non-Local means filter is built up on the concept that the image characteristics are likely to appear itself within some neighborhood of the pixel. The denoising is aimed at removing the noise and preserving the image details. The NL-means filter is an extension of the neighborhood filtering algorithm. The NL-means filter computes the denoised pixel by the weighted sum of the surrounding pixels. Thus the actual pixel values can be estimated from the noise contaminated images. The neighborhood filter proposed by Yaroslavsky, averages only similar gray level pixels contained in the spatial neighbourhood \( B_\sigma \) and it is given by

\[
YNF_{h,\sigma}v(x) = \frac{1}{c(x)} \int_{B_{\sigma}(x)} v(y)e^{-\frac{(y-x)\cdot(y-x)}{h^2}} dy \quad (1)
\]

where \( x \in \text{image } \Omega \), is the normalization factor and \( h \) controls pixel similarity. The neighborhood filter proposed by Yaroslavsky is less popular than more recent versions such as the SUSAN filter and the Bilateral filter. In both the algorithms instead of considering a fixed spatial neighborhood \( B_\sigma(x) \), the distance to the reference pixel is weighted,

\[
SNF_{h,\sigma}v(x) = \frac{1}{c(x)} \int_{B_{\sigma}(x)} v(y)e^{-\frac{(y-x)\cdot(y-x)}{\sigma^2h^2}} dy \quad (2)
\]

where, \( c(x) = \int_{B_{\sigma}(x)} v(y)e^{-\frac{(y-x)\cdot(y-x)}{\sigma^2h^2}} dy \)

is the normalization factor and \( \sigma \) is spatial filtering parameter. The limitation of these filters is that they consider only the gray level values around the pixel of interest. As a result it is not robust when these values are noisy. These types of filters also maintain sharp boundaries because they average pixels belonging to the same region as reference pixel. Baudes et al. have developed the neighborhood filters to a new class called it as the Non-Local –Means. It is based on the assumption that an image contains a self similarity. This property of the images is used to calculate the pixel weights for filtering the noisy images. It is not necessary that the similar pixels may lie close to the given pixel. So it needs to scan the entire image for a similar pixel which is similar to the pixel to be denoised. The similarity is evaluated by comparing a whole window around each pixel, not just the pixel value. Denoising is performed by calculating the average gray level value of the most resembling pixels. Since the noise is typically independently and identically distributed and the image pixels are highly correlated, averaging of these pixels results in noise removal and produces a pixel value which is similar to the original value.

Consider a noisy image \( x = \{x(i)|i \in I\} \), the estimated value \( NL(i) \) for a pixel \( i \), is calculated as the weighted average of all pixel intensities \( x(j) \) in the image \( I \),

\[
NL(i) = \sum_{j \in I} w(i,j)v(j) \quad (3)
\]

Where \( w(i,j) \) is the weight assigned to the value \( x(j) \) for denoising the pixel \( i \). By the traditional definition of the NL-means filter, pixel intensities of each pixel in an image is compared to every other pixels in the entire image, due to the computational complexity involved, the pixels considered in the weighted average is confined to neighborhood search window \( Si \) centered at pixel \( i \).

In digital images the similarity is measured as a decreasing function of the weighted Euclidean distance \( ||v(N_i)-v(N_j)||_{2,\sigma}^2 \), where \( \sigma > 0 \) is the standard deviation of the Gaussian kernel. Due to the fast decay of the exponential kernel, large Euclidean distance will lead to nearly zero weights acting as an automatic threshold. As the NL-means filter considers the geometrical configuration in a whole neighborhood along with the gray level in a single point, it gives a robust denoising performance as compared to the neighborhood filters.

**NL Means and Its Method Noise Thresholding**

The image denoising method used here is a combination of Non-local means filter and its method noise thresholding using wavelets. The method noise is defined as the difference between the original image and the denoised image. The method noise can be mathematically expressed as,

\[
MN = I - IF \quad (4)
\]

Where, \( A \) is the noisy image and \( IF \) is the denoised image. The NL-means filter removes the noise and cleans the edges without losing too many fine structures and details. The NL-means fitter is very much effective at low noise levels, but the performance decreases as the noise increases. The performance decreases because the similar local patches which are used to find the pixel weights are also noisy. At high noise levels, the NL-means filter causes blurring to the image during the process of noise removal. Therefore the image details will get lost. As a result the method noise \( MN \) will be a combination of noise and some image details. Hence, the method noise \( MN \) will be a combination of image details \( D \) and white Gaussian noise \( N \), and it can be expressed as
\[ MN = D + N \] (5)

Now the image details \( D \), which contains the original image features that are removed by the NL-means filter have to be estimated and incorporated with the NL-means filtered image to et a superior image. Let's consider \( Y \) as the noisy wavelet coefficient as the true wavelet coefficient and \( W \) as the independent Gaussian noise in the wavelet domain. Our aim is to estimate the true wavelet coefficient \( W \) from \( Y \), using a proper threshold value which minimizes the Mean square error. In the proposed method the Bayes' Shrink method proposed by Chang et al. have been used for the wavelet coefficient thresholding as this method has a better MSE than other methods. The Bayes Shrink is an adaptive soft thresholding method. This method is adaptive to each sub-band. The threshold for a given sub-band is derived by minimizing the Bayesian risk, given by

\[ T = \frac{\sigma^2_n}{\sigma_w} \] (6)

where \( \sigma^2_n \) is the noise variance which is estimated from the sub-band HH1 by a robust median estimator[3] given by,

\[ \sigma^2_n = \frac{\text{Median}(|Y_{ij}|)}{0.6745}, Y_{ij} \in \{HH1\} \] (7)

**Lanczos Interpolation**

The commonly used interpolation techniques are based on nearest neighbors (include nearest neighbor, bilinear, bicubic, and Lanczos). Lanczos resampling, invented by Cornelius Lanczos, is an interpolation function that is used extensively in the arena of digital signal processing. It is basically a Fourier kernel. Its essentiality is for smoothly interpolating the value of a digital signal between its samples. Each of the given signal’s samples is effectively mapped to give a translated and scaled copy of the Lanczos kernel. A Lanczos kernel is nothing but a sinc function apodized by the central hump of a dilated sine function19. The sum of these shifted and scaled kernels is then evaluated at the requisite points. Lanczos resampling is also referred to as Lanczos filter. Lanczos resampling finds application for incrementing the sampling rate of a digital signal. It finds application in digital image processing for performing multidimensional interpolation. The Lanczos interpolation (windowed form of a sinc filter) is better than its counterparts (including nearest neighbor, bilinear, and bicubic) due to its increased ability to detect edges and linear features. It also offers the best compromise in terms of reduction of aliasing, sharpness, and ringing19. The Lanczos-2 kernel is used here. Lanczos interpolation uses a neighborhood of the 2n×2n nearest mapped pixels. A two-dimensional Lanczos filter is nonseparable, so the complexity of Lanczos interpolation is \( O(N^2 \times 4n^2) \).

The higher-frequency components have been preserved in this technique. The intermediate process of adding the thresholded method noise, containing the details lost due to NLM filtering, generates significantly sharper and clearer final image. Not only visual comparison but an also quantitative comparison is confirming the superiority of the proposed method. Peak signal to noise ratio (PSNR) and Image Quality index (IQI) have been implemented in order to obtain some quantitative results for comparison.

![Figure 1: Proposed Image Enhancement Model](image)

**RESULTS AND DISCUSSION**

To evaluate the performance of the proposed image enhancement method, we use different test images. The test is conducted on images of different noise levels. The proposed algorithm is compared with other methods such as Nearest Neighbour interpolation, Bilinear interpolation, and Bicubic interpolation. The performance is evaluated using the quality measures such as, Peak Signal to Noise Ratio (PSNR) and Image Quality Index Index(IQI). The IQI of the denoised image is defined as a product of three factors: loss of correlation, luminance distortion and contrast distortion. Here the image quality is measured in terms of PSNR. Peak signal-to-noise ratio (PSNR) has been implemented in order to obtain some quantitative results for comparison. PSNR is usually expressed in terms of logarithmic decibel value. The PSNR can be calculated as

\[ \text{PSNR} = 10 \log_{10} \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} 255^2}{\sum_{i=1}^{M} \sum_{j=1}^{N} (x(i,j) - \hat{x}(i,j))^2} \] (8)

Where \( x \) is the original image and \( \hat{x} \) is the processed image. A higher PSNR generally indicates that the reconstruction is of higher quality. The IQI is expressed as

\[ \text{IQI} = \frac{4m_m \sigma B}{(m_m^2 + m_B^2)(\sigma^2_s \sigma^2_B)} \] (9)
Figure 2 shows the resolution enhanced images of different interpolation methods. We can observe that more jagged edges or blurring are produced in the interpolated images obtained by the bilinear interpolation and bicubic interpolation. It clearly shows that proposed method gives a sharper image. The performance of the proposed algorithm is superior compared with other interpolation methods. Table I shows that the proposed method has a higher PSNR compared to all other methods and the higher PSNR indicates a good quality image.

Table I: PSNR Comparison of Different Resolution Enhancement Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearest Neighbour</td>
<td>23.3366</td>
</tr>
<tr>
<td>Bilinear</td>
<td>24.8843</td>
</tr>
<tr>
<td>Bicubic</td>
<td>26.5523</td>
</tr>
<tr>
<td>Proposed Method</td>
<td>26.6032</td>
</tr>
</tbody>
</table>

Table II: Comparison of NLM and Proposed Enhancement Method

<table>
<thead>
<tr>
<th>σ</th>
<th>PSNR (NLM)</th>
<th>PSNR (NLFMT)</th>
<th>IQI (NLM)</th>
<th>IQI (NLFMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>32.2800</td>
<td>32.2067</td>
<td>0.9906</td>
<td>0.9905</td>
</tr>
<tr>
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<td>29.4076</td>
<td>0.9827</td>
<td>0.9836</td>
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<td>27.5404</td>
<td>0.9749</td>
<td>0.9760</td>
</tr>
<tr>
<td>40</td>
<td>25.6624</td>
<td>25.9505</td>
<td>0.9666</td>
<td>0.9677</td>
</tr>
</tbody>
</table>

Figure 2: Interpolated images of a typical satellite image (1836x1544) (a) Original image (b) Bilinear (c) Bicubic (d) Proposed method

Figure 3: Satellite image (1836x1544) (a) Original image (b) Noise added image (c) NLM filtered image (d) Proposed method (e) Method noise of NLM filter (f) Method noise of proposed filter

CONCLUSION

In the field of satellite imaging, high resolution images are of great importance for the accurate analysis and identification of details from imagery. In this paper, we present an efficient technique for the enhancement of satellite images using lanczos interpolation method and the Non-local means method noise thresholding. The objective quality measures such as, Peak Signal to Ratio (PSNR) and Image Quality Index (IQI) is used to evaluate the performance of the proposed method with other interpolation methods such as nearest neighbor, bilinear and bicubic interpolation. The visual and the quantitative
analysis of the experimental results show that the proposed method have good PSNR and IQI values and is superior than other enhancement techniques.

REFERENCES


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