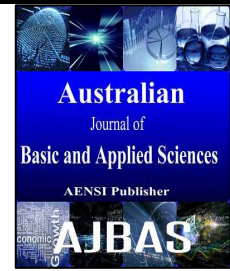




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Resolution Magnification Technique for Satellite Images Using DT- CWT and NLM

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ABSTRACT

Resolution enhancement (RE) schemes (which are not based on wavelets) suffer from the drawback of losing high-frequency contents which results in blurring. The discrete-wavelet-transform-based (DWT) RE scheme generates artifacts (due to a shift-variant property). A wavelet domain approach which is based on dual-tree complex wavelet transform (DT-CWT) and nonlocal means (NLM) is proposed for RE of the satellite images. Satellite image(input) is decomposed by DT-CWT (which is nearly shift invariant) to obtain high-frequency(HF) subbands. The HF subbands and the low-resolution (LR) input image are interpolated using the Lanczos interpolator. The HF subbands are passed through an NLM filter to satisfy the artifacts generated by DT-CWT (despite of it's nearly shift invariance). The filtered HF subbands and the LR input image are combined using inverse DT-CWT to obtain enhanced resolution image. Objective and subjective analyses reveal the superiority of the proposed technique over the conventional and state-of-the-art RE techniques.

INTRODUCTION

Resolution (spatial, spectral, temporal) is the limiting factor for the utilization of remote sensing data (satellite image, etc.). Spatial and spectral resolutions of unprocessed satellite images are related (a high spatial resolution is associated with a low spectral resolution and vice-versa) with each other. Therefore, spectral, as well as spatial, RE is desirable.

Interpolation has been widely used for RE purposes. Commonly used interpolation techniques are based on nearest neighbor, bilinear, bicubic, and Lanczos. The Lanczos interpolation (windowed form of a sinc filter) is superior than its counter parts (including nearest neighbor, bilinear, and bicubic) due to increased ability to detect edges and other linear features. It also offers the best compromise interms of decrease in aliasing, sharpness, and minimal ringing.

RE schemes (which are not based on wavelets) suffer from the drawback of losing HF contents (which results in blurring).

RE in the wavelet domain is a new research area, many algorithms discrete wavelet transforms (DWT), stationary wavelet transforms (SWT), and dual-tree complex wavelet transform (DT-CWT) have been proposed recently. An RE scheme was suggested using DT-CWT and bicubic interpolations and results were examined with contrast (shown superior) with the conventional schemes (i.e, nearest neighbor, bilinear, and bicubic interpolations and wavelet zero- padding).Very recently, in a scheme based on DWT and bicubic interpolation was proposed, and results were compared with the conventional schemes and the state-of-art schemes (wavelet zero padding and cyclic spinning and DT-CWT). Note that , DWT is shift variant, which will cause man-made

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object in the RE image, and has a lack in direction; however, DT-CWT is almost shift and rotation invariant. DWT based RE schemes generate distortions (due to DWT shift-variant property).

In this letter, DT-CWT-based non-local-means based RE (DT-CWT-NLM-RE) technique is proposed, using DT-CWT, Lanczos interpolation, and NLM. Note that DT-CWT is nearly shift invariant and directional selective. Also, DT-CWT preserved the usual properties of perfect reconstruction with well-balanced frequency responses. As a result, DT-CWT gives promising results after the modification of the wavelet coefficients and provides less distortions, as compared with traditional DWT. Since the Lanczos filter offers less aliasing, edge sharpness, and minimal ringing, therefore, it is a good choice for the RE. NLM filtering is used to further enhance the performance of DT-CWT-NLM-RE by reducing the distortions. The results for spatial RE of optical images are compared with the best performing techniques.

Preliminaries:

A. NLM Filtering:

NLM filter (an extension of neighbourhood filtering algorithms) is based on the assumption that the image content is likely to repeat itself within some neighbourhood (in the image) and in neighbouring frames. It computes denoised pixel $x(p, q)$ by the weighted sum of the surrounding in pixels of $Y(p, q)$ (within the frame and in the neighbouring frames). This feature provides a way to estimate the pixel value from noisy images. In a 3-D NLM algorithm, the estimate of a pixel at position (p, q) is

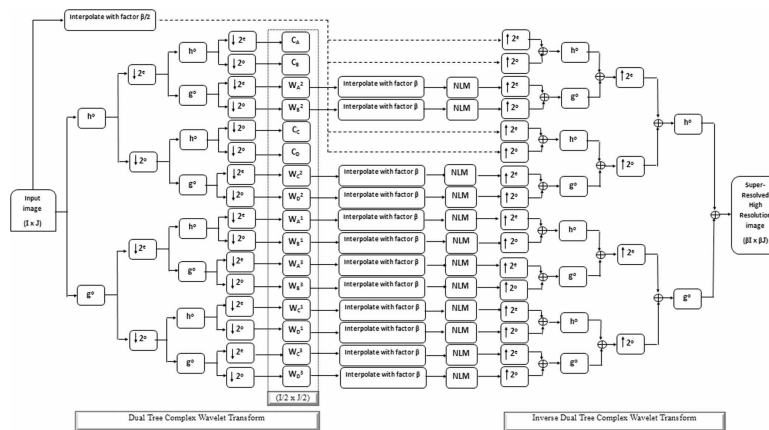


Fig. 1: Block diagram of proposed DT-CWT RE algorithm.

$$x(p, q) = \frac{\sum_{m=1}^M \sum_{(r,s) \in N(p,q)} Y_m(r, s) K_m(r, s)}{\sum_{m=1}^M \sum_{(r,s) \in N(p,q)} K_m(r, s)} \quad (1)$$

Where m is the frame index, and N represents the neighbourhood of the pixel at location (p, q) . K values are the filter weights, i.e,

$$K(r, s) = \exp \left\{ -\frac{\|V(p, q) - V(r, s)\|_2^2}{2\sigma^2} \right\} \times f \left(\sqrt{(p-r)^2 + (q-s)^2 + (m-1)^2} \right) \quad (2)$$

Where V is the window [usually a square window centered at the pixels $Y(p, q)$, $Y(r, s)$] of pixel values from the geometric neighbourhood of pixels $Y(p, q)$, $Y(r, s)$, σ is a filter coefficient, $f(\cdot)$ is a geometric distance function.

B. NLM-RE:

RE is achieved by modifying the NLM with following model :

$$L_m = IJQX + n \quad (3)$$

where L_m is the vectorized low-resolution (LR) frame, I is a decimation operator, J is a blurring matrix, Q is a warping matrix, X is a vectorized high-resolution (HR) image, and n denotes Gaussian white noise. The aim is to restore the X from a series of L . The Penalty function is defined as,

$$\epsilon^2 = \frac{1}{2} \sum_{m=1}^M \|IJQx - Y_m\|_2^2 + \lambda R(x) \quad (4)$$

Where R is a regularization term, λ is a scale coefficient, x is a targeted image, and Y_m is the LR image(input). In total variation kernel is chosen to replace R , which is acting as an image deblurring kernel. To simplify this, a separation of the problem is done by minimizing

$$\epsilon_{\text{fusion}}^2(Z) = \frac{1}{2} \sum_{m=1}^M (IQZ - L_m)^T O_m (IQZ - L_m) \quad (5)$$

Where Z is the blurred version of targeted image, and O_m is weight matrix, which is followed by minimizing a deblurring equation i.e,

$$\epsilon_{\text{RE}}^2(X) = \|JX - Z\|_2^2 + \lambda R(Z). \quad (6)$$

A pixel-wise solution can be obtained as,

$$\hat{z} = \frac{\sum_{m=1}^M \sum_{(r,s) \in N(p,q)} Y_m^r(r,s) K_m^r(r,s)}{\sum_{m=1}^M \sum_{(r,s) \in N(p,q)} K_m^r(r,s)} \quad (7)$$

where the superscript r refers to the HR coordinate. Instead of estimating the targeted pixel position in the nearby frames, this algorithm considers all the possible positions where pixel may appear. Therefore, motion estimation is avoided. The equation apparently resembles, but has some differences when compared. The weight estimation of this should be modified because K 's corresponding matrix O must be of the same size as HR image. Therefore, simple up scaling process to patch V is must before computing K . The total number of pixel Y should be equal to the number of weights K . So, a zero-padding interpolation is applied to L before fusing all the images.

Proposed Technique:

There are two assumptions made by most denoising algorithms about the noisy image. This could result in blurring and loss of fine detail in the denoised image. The first assumption is that the noisy image comprises of both low and high frequencies. The noise can be classified as non-smooth because of the high frequencies contained in it. The second assumption is that the original image only contains low frequencies. i.e. images do not contain fine detail.

The Gaussian and the Wiener approaches also make some of these assumptions. They also attempt to denoise the noisy image by removing the HF from the lower frequencies. However, some of the images may not be smooth. They can contain fine details and structures which contain HF. Because these methods can't differentiate between the HF of the original image and the noise, the HF of original image will be lost. This will result in blurring. In addition to this the low frequencies of the noise will still remain as denoised image. To prevent this, Buade suggested a better approach. The NLM approach does not make the two assumptions mentioned previously instead it assumes that the image contains an extensive amount of self-similarity.

In our proposed algorithm (DT-CWT- NLM - RE), we decompose the LR image(input) (for the multichannel case, each channel is separately treated) in different subbands (i.e, C_i , W_j ; where $i \in \{A, B, C, D\}$ and $j \in \{1, 2, 3\}$) by using the DT-CWT, as shown in the Fig. 1. C_i values are the image coefficient subbands, and W_j are the wavelet coefficient subbands. The subscripts A, B, C, and D represent the coefficients at the 2e-r and e-c index, the o-r and e-c index, the e-r and o-c index and the o-r and o-c index, respectively, whereas h and g represent the low-pass and high-pass filters, respectively. The superscript e and o represent the even and odd indices, and r and c represents row and column respectively.

W_j values are interpolated by factor β using the Lanczos interpolation (having good approximation capabilities) and combined with the $\beta/2$ -interpolated LR input image. Since C_i contains low-pass-filtered image of the LR input image, therefore, high-frequency information is lost. To cater for it, we have used the LR input image instead of C_i . Although the DT-CWT is almost shift invariant, however, it may produce artifacts after the interpolation of W_j .

Therefore, to reduce these artefacts, NLM filtering is used. All interpolated W_j values are passed through the NLM filter. Then, we apply the inverse DT-CWT to these filtered subbands along with the interpolated LR input image to reconstruct the HR image. The results presented show that the proposed DT-CWT-NLM-RE algorithm performs better than the existing wavelet-domain RE algorithms in terms of the peak-signal-to noise ratio (PSNR), the MSE, and the Q -index

RESULTS AND DISCUSSION

To ascertain the effectiveness of the proposed DT CWTNLM- RE algorithm over other wavelet-domain RE techniques, different LR optical images obtained from the Satellite Imaging Corporation webpage were tested. The image of Palm island is chosen here for comparison with existing RE techniques. Note that the input LR

image has been obtained by Downsampling the original HR by a factor of 4. Fig. 1 shows the original “palm island” image, the downsampled input image, and the images obtained using , DWT-RE , SWT-DWT-RE, and proposed DTCWT- NLM-RE shows the difference of the original image and images obtained using SWT-RE, DWT-SWT-RE, and proposed DT-CWTNLM- RE.

It can be seen that the results of the proposed algorithm DT-CWT-NLM-RE are much better than the RE images obtained using other techniques. Table shows that the proposed techniques provide improved results in terms of PSNR, as compared with other techniques.

Table 1: PSNR Comparison.

Method	PSNR
DiscreteWavelet Transform	13.7802
DiscreteWavelet Transform-Stationary Wavelet Transform	14.7527
Dual Tree Comple Wavelet Transform-Non local Means Filter	17.5895

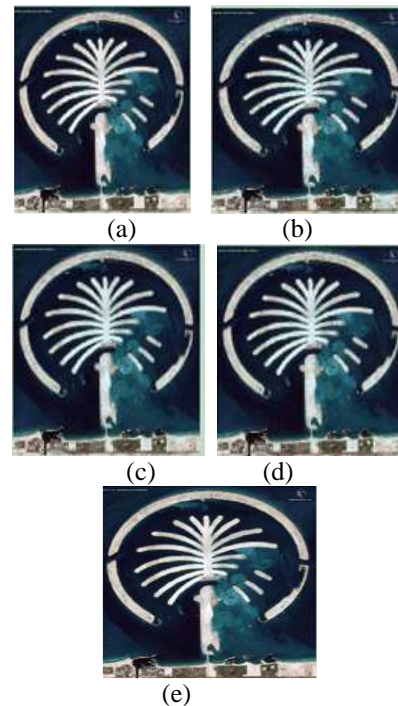


Fig. 2: (a) Low Resolution Image(256*256). (b) Pre Processing Image. (c) Existing DWT. (d) Existing DWT-SWT. (e) Proposed DT-CWT and NLM filter.

Conclusion:

An RE technique based on DT-CWT and an NLM filter has been proposed. The technique decomposes the LR input image using DT-CWT. Wavelet coefficients and the LR input image were interpolated using the Lanczos interpolator. DT-CWT is used since it is nearly shift invariant and generates less artifacts, as compared with DWT. NLM filtering is used to overcome the artifacts generated by DT-CWT and to further enhance the performance of the proposed technique in terms of MSE, PSNR, and Q -index. Simulation results highlight the superior performance of proposed techniques.

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