IMAGE RESOLUTION ENHANCEMENT USING BICUBIC AND SPLINE INTERPOLATION TECHNIQUES

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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 DWT shift-variant property). A wavelet-domain approach based on dual-tree complex wavelet transform (DT-CWT) and nonlocal means (NLM) for RE of the satellite images. A satellite input image is decomposed by DT-CWT (which is nearly shift invariant) to obtain high-frequency sub bands. The high-frequency sub bands and the low-resolution (LR) input image are interpolated using the Lanczos interpolator. Bicubic Interpolation look’s best with smooth edges and much less blurring than the Lanczos result. The high-frequency sub bands are passed through an NLM filter to cater for the artifacts generated by DT-CWT (despite of its nearly shift invariance). The filtered high-frequency sub bands and the LR input image are combined using inverse DT-CWT to obtain a resolution-enhanced image. Objective and subjective analyses reveal the superiority of the proposed technique over the conventional and state-of-the-art RE techniques.

Index Terms—Dual-tree complex wavelet transform (DT-CWT), Lanczos interpolation, and resolution enhancement (RE), shift variant, bicubic spline interpolation.

I. INTRODUCTION

The principal objective of image enhancement is to process a given image so that the result is more suitable than the original image for a specific application. It accentuates or sharpens image features such as edges, boundaries, or contrast to make a graphic display more helpful for display and analysis. The enhancement doesn't increase the inherent information content of the data, but it increases the dynamic range of the chosen features so that they can be detected easily. The greatest difficulty in image enhancement is quantifying the criterion for enhancement and, therefore, a large number of image enhancement techniques are empirical and require interactive procedures to obtain satisfactory results. Image enhancement methods can be based on either spatial or frequency domain techniques.

II. IMAGE PROCESSING

In imaging science, image processing is any form of signal processing for which the input is an image, such as a Photo-graph or video frame; the output of image processing may be either an image or a set of characteristics or parameters related to the image. Most of the image processing Techniques involve treating the image as a two dimensional signal and applying standard signal-processing Techniques to it. Image processing usually refers to digital image processing, but optical and analogue image processing also are possible. These processing methods are based only on the intensity of single pixels.
III. IMAGE ENHANCEMENT METHOD

Enhancement of the image is necessary to improve the visibility of the image subjectively to remove unwanted noise, to improve contrast and to find more details. Mainly there are two major approaches. They are spatial domain, where statistics of grey values of the image are manipulated and the second is frequency domain approach; where image processing. Basically, the idea behind Image enhancement is to bring out detail that is unclear, or simply to highlight certain interesting features of an image.

A familiar example of enhancement is when we increase the contrast of an image and it looks better. Thus, Enhancement is a very subjective area of image processing. Image enhancement can improve a satellite image which has complete information but is not visible. There have been several techniques for enhancing a satellite image such as histogram equalization technique, discrete cosine transform technique etc.

IV. TECHNIQUES

A. NLM Filtering

The NLM filter (an extension of neighborhood filtering algorithms) is based on the assumption that image content is likely to repeat itself within some neighborhood (in the image \[ Y(p, q) \] (within frame and in the neighboring frames) \[ Y \]). This Feature provides a way to estimate the pixel value from noise contaminated Images.

Suppose the function values \( f \) and the derivatives \( f_x, f_y \) and \( f_{xy} \) are known at the four corners \( (0, 0), (1, 0), (0, 1), \) and \( (1, 1) \) of the unit square. The interpolated surface can then be written

\[
p(x, y) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij} x^i y^j
\]

The interpolation problem consists of determining the 16 coefficient of \( a_{ij} \). Matching \( p(x, y) \) with the function values yields four equations,

\[
f(0,0) = p(0,0) = a_{00}
\]
\[
f(1,0) = p(1,0) = a_{00} + a_{10} + a_{20} + a_{30}
\]
\[
f(0,1) = p(0,1) = a_{00} + a_{01} + a_{02} + a_{03}
\]
\[
f(1,1) = p(1,1) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij}
\]

Likewise, eight equations for the derivatives in the \( x \)-direction and the \( y \)-direction

\[
f_{x}(0,0) = p_{x}(0,0) = a_{10}
\]
\[
f_{x}(1,0) = p_{x}(1,0) = a_{10} + 2a_{20}
\]
\[
f_{x}(0,1) = p_{x}(0,1) = a_{10} + a_{11}
\]
\[
f_{x}(1,1) = p_{x}(0,1) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij}
\]
\[
f_{y}(0,0) = p_{y}(0,0) = a_{01}
\]
\[
f_{y}(0,1) = p_{y}(0,1) = a_{01} + a_{11}
\]
\[
f_{y}(0,1) = p_{y}(0,1) = a_{01} + 2a_{02}
\]
\[
f_{y}(1,1) = p_{y}(1,1) = \sum_{i=0}^{3} \sum_{j=0}^{3} a_{ij}
\]
and four equations for the cross derivative $f_{xy}$.

\begin{align*}
f_{xy}(0,0) &= p_{xy}(0,0) = a_{11} \\
f_{xy}(1,0) &= p_{xy}(1,0) = a_{11} + 2a_{21} + 3a_{31} \\
f_{xy}(0,1) &= p_{xy}(0,1) = a_{11} + 2a_{12} + 3a_{13} \\
f_{xy}(1,1) &= p_{xy}(1,1) = \sum_{i=1}^{3} \sum_{j=1}^{3} a_{ij}ij
\end{align*}

Where the expressions above have used the following identities, accomplished by patching together such bicubic surfaces, ensuring that the derivatives match on the boundaries.

\begin{align*}
p_y(x,y) &= \sum_{i=1}^{3} \sum_{j=1}^{3} a_{ij}x^{i-1}y^{j} \\
p_{xy}(x,y) &= \sum_{i=1}^{3} \sum_{j=1}^{3} a_{ij}x^{i-1}y^{j-1}
\end{align*}

This procedure yields a surface on the unit square which is $p(x,y) = [0,1] \times [0,1]$ continuous and with continuous derivatives. Bicubic interpolation on an arbitrarily sized regular grid can then be

If the derivatives are unknown, they are typically approximated from the function values at points neighboring the corners of the unit square, e.g. using finite differences.

Grouping the unknown Parameters $a_{ij}$ in a vector,

$$\alpha = [a_{00} \ a_{10} \ a_{20} \ a_{30} \ a_{01} \ a_{11} \ a_{21} \ a_{31}]$$

and letting

$$x = [f(0,0)f(1,0)f(0,1)f(1,1) \ f_x(0,0)]$$

The problem can be reformulated into a linear equation $A\alpha = x$ where its inverse

\begin{align*}
\sum_{i=1}^{3} a_{ij}x^{i-1}y^{j} &= \sum_{i=1}^{3} a_{ij}x^{i-1}y^{j-1}
\end{align*}
B. NLM-RE:

Bicubic spline interpolation requires the solution of the linear system described above for each grid cell. An interpolator with similar properties can be obtained by applying a convolution with the following kernel in both dimensions:

$$W(x) = \begin{cases} (a+2)|x|^3 - (a+3)|x|^2 + 1 & \text{for } |x| \leq 1 \\ a|x|^3 - 5a|x|^2 + 8a|x| - 4a & \text{for } 1 < |x| < 2 \\ 0 & \text{otherwise} \end{cases}$$

Where ‘a’ is usually set to -0.5 or -0.75. Note that $W(0) = 1$ and $W(n) = 0$ for all non-zero integers $n$.

This approach was proposed by Keys who showed that $a = -0.5$ (which corresponds to cubic spline) produces third-order convergence with respect to the original function $^{[1]}$.

If we use the matrix notation for the common case $a = -0.5$, we can express the equation in a friendlier manner:

$$p(t) = \frac{1}{2} \begin{bmatrix} 0 & 2 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 2 & -5 & 4 & -1 \\ -1 & 3 & -3 & 1 \end{bmatrix} \begin{bmatrix} a_{-1} \\ a_0 \\ a_1 \\ a_2 \end{bmatrix}$$

For $t$ between 0 and 1 for one dimension. For two dimensions first applied once in $x$ and again in $y$:

$$b_{-1} = p(t_x, a_{-1}, a_{-1}, a_{0}, a_{1}, a_{2})$$
$$b_0 = p(t_x, a_{0}, a_{0}, a_{1}, a_{1}, a_{2})$$
$$b_1 = p(t_x, a_{1}, a_{0}, a_{1}, a_{1}, a_{2})$$
$$b_2 = p(t_x, a_{2}, a_{0}, a_{1}, a_{1}, a_{2})$$

$$p(x, y) = p(t_y, b_1, b_0, b_1, b_2)$$

NLM Filtering on the square $[0,3] \times [0,3]$ consisting of 9 unit squares patched together. Color indicates function value. The black dots are the locations of the prescribed data being interpolated. Note how the color samples are not radially symmetric.

NLM RE filtering on the same dataset as above. Derivatives of the surface are not continuous over the square boundaries.
V. PROPOSED TECHNIQUES

In the proposed algorithm (Bicubic Spline Interpolation), we decompose the LR input image (for the multichannel case, each channel is separately treated) in different sub bands (i.e., Ci and Wji , where i∈{A,B,C,D} and j∈{1, 2, 3}) by using DT-CWT, as shown in Fig. 1. Ci values are the image coefficient sub bands, and WjI are the wavelet coefficient subbands. The subscripts A, B, C, and D represent the coefficients at the even-row and even-column index, the odd-row and even-column index, the even-row and odd-column index and the Odd-row and odd-column index, respectively, whereas h and g represent the low-pass and high-pass filters, respectively. The superscript e and o represent the event and odd indices, respectively. Wji values are interpolated by factor β using the Lanczos interpolation (having good approximation capabilities) and combined with the β/2-interpolated LR input image. Since Ci 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 Ci. Although the DT-CWT is almost shift invariant [14], however, it may produce artifacts after the interpolation of Wji. Therefore, to cater for these artifacts, NLM filtering is used. All interpolated Wji values are passed through the NLM filter. Then, we apply the inverse DT-CWT to these filtered sub bands along with the interpolated LR input image to reconstruct the HR image.

Then, we apply the inverse DT-CWT to these filtered sub bands along with the interpolated LR input image to reconstruct the HR image. The results presented show that the proposed Bicubic Spline Interpolation 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.
VI. RESULTS AND DISCUSSION

To ascertain the effectiveness of the proposed Bicubic Spline Interpolation algorithm over other wavelet-domain RE techniques, different LR optical images obtained from the Satellite Imaging Corporation webpage [1] were tested. The Digital Aerial Photograph chosen here for comparison with existing RE techniques. Note that the input LR image has been obtained by down-sampling the original HR by a factor of 4 shows the original sampled input image, and the images obtained using SWT-RE [8], DWT-RE [7], SWT-DWT-RE [8], Lanczos interpolation, DT-CWT-RE [9], proposed DT-CWT-RE, and proposed Bicubic Spline Interpolation.

Table 1 shows the difference of the original Image and images obtained using SWT-RE [8], DWT-RE[7], SWT-DWT-RE [8], Lanczos-RE, Bicubic Spline Interpolation.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>MSE</th>
<th>PSNR</th>
<th>Q-Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWT-RE</td>
<td>0.0464</td>
<td>13.332</td>
<td>0.9994</td>
</tr>
<tr>
<td>DWT-RE</td>
<td>0.0419</td>
<td>13.782</td>
<td>0.0991</td>
</tr>
<tr>
<td>DT-CWT-RE</td>
<td>0.0215</td>
<td>16.66</td>
<td>0.9986</td>
</tr>
<tr>
<td>PROPOSED Bi cubic Spline Interpolation</td>
<td>0.0174</td>
<td>17.568</td>
<td>0.9999</td>
</tr>
</tbody>
</table>

VII. CONCLUSION

An RE technique based on Bicubic Spline Interpolation has been proposed. The technique decomposes the LR input image using DT-CWT. Wavelet coefficients and the LR input image are interpolated using the Bicubic Spline 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.

REFERENCES


[17] M. Protter, M. Elad, H. Takeda, and P. Milanfar, “Generalizing the nonlocal-