Image denoising algorithm based on improved filter in Contourlet domain

HongJun Li, ZhiMin Zhao*

Nanjing University of Aeronautics and Astronautics, Nanjing, P.R. China

{lihongjun103, zhaozhimin*}@nuaa.edu.cn

Abstract

In this paper we analyzed directional filter and pyramid filter in Contourlet transform, confirmed the different choices of filters directly affect the image denoising result, so we constructed a kind of compactly supported biorthogonal filter based on human visual Characteristics and applied it to image denoising. The new Contourlet transform algorithm can improve the result of image denoising, and the most important improvement is the great superiority shown by new Contourlet domain hidden markov tree (CHMT) algorithm in image denoising. The denoised images by using new CHMT algorithm have been improved on PSNR.

Keywords: Image denoising, Contourlet transform, compactly supported biorthogonal filter, new CHMT algorithm

1. Introduction

In the image processing, if the filter has the characteristic of orthogonal, the decompose coefficient will correlation both scale. But its defection is no liner phase, so it cannot complete reconstruct. However, biorthogonal filter gives up some part of orthogonal Characteristic but has line phase, so that the image biorthogonal decompose is good at marginal maintaining. The difference of filters directly affects the image denoising result.

Contourlet transform has been widely used in image denoising domain [1] [2], how to choose appropriate filters in Contourlet domain is a problem. According to the Contourlet transform which D.D.-Y.Po and M.N.Do [3] proposed, this article analysed the filters in several algorithms and proposed an improved filter. The result of image denoising showed that the filter this article proposed has feasibility and superiority.

In section 2 of this article we introduced the Contourlet transform, in section 3 we analyzed the different filters affect the image denoising result, in section 4 we built a kind of compactly supported biorthogonal filter based on human visual Characteristics, in section 5 we applied the filter which section 4 has proposed to different algorithms on image denoising, then followed by conclusion and future work in section 6.

2. Contourlet transform

Two-dimensional wavelets are only good at catching zero-dimensional or point discontinuities, two-dimensional piecewise smooth functions resembling images have one-dimensional discontinuities intuitively, wavelets in 2-D obtained by a tensor-product of one dimensional wavelets will be good at isolating the discontinuities at edge points, but will not see the smoothess along the contour. This indicates that more powerful representations are needed in higher dimensions.

Contourlet not only has the multi-resolution and time-frequency localization properties of wavelet, but also shows a very high degree of directionality and anisotropy. Contourlet transform involves basis functions that are oriented at any power of two degree of directions with flexible aspect ratios. With such richness in the choice of basis functions, Contourlet can represent any one-dimensional smooth edges with close optimal efficiency.
The Contourlet transform is constructed as a combination of Laplacian Pyramid (LP) and Directional Filter Bank (DFB). Conceptually, the Laplacian Pyramid iteratively decomposes a 2-D image into low pass and high pass subbands, and the DFB is applied to the high pass subbands to further decompose the frequency spectrum. If we use ideal filters, the Contourlet transform will decompose the 2-D frequency spectrum into trapezoid-shaped regions. In practice, if non-ideal filters are used, the result of Contourlet transform will not have the desired sharp frequency domain localization. So choose a good filter in the Contourlet transform is of most importance. This article mainly analyses the pyramid filter and the directional filter; we will apply different filters to several algorithms to compare their denoising results in the following section.

3. Different filters affect the results of image denoising

In practice, if non-ideal filters are used, the resulting Contourlet will not have good performance. So we analyze the different filters in Contourlet in order to find a better one to improve the algorithms. In experimental process, there are many kinds of orthogonal wavelets and biorthogonal wavelets, we chose some of them in Contourlet transformation [5]: such as 'Daubechies 9/7', '5/3', 'Burt', 'haar' and 'pkvaN' and so on. Through the massive experiments, we discovered that different combination of filters have different results.

The experiments chose Optical image 'lean' to test, we applied different filters to image denoising such as: Wavelet transform (WT), Contourlet transform (CT), Contourlet HMT (CHMT) [6]. In Table 1 we chose the optical images 'lean' of size of 256*256. The noise standard deviation $\sigma$ is 30. Table 1(left) is the results of different image denoising algorithm with the same directional filter (DF) 'pkva' under different pyramid filter (PF) combination. The combinations of pyramid filter ‘9/7’ and the directional filter ‘pkva’ gain good result. Table 1(right) is the results of different image denoising algorithm with the same pyramid filter ‘9/7’ under different directional filter combination. The experiments proved that the combination of the directional filter ‘pkva’ and the pyramid filter ‘9/7’ super than others.

<table>
<thead>
<tr>
<th>PF</th>
<th>WT</th>
<th>CT</th>
<th>CHMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/7</td>
<td>22.07</td>
<td>24.20</td>
<td>25.37</td>
</tr>
<tr>
<td>5/3</td>
<td>21.92</td>
<td>24.19</td>
<td>24.83</td>
</tr>
<tr>
<td>Burt</td>
<td>21.93</td>
<td>24.07</td>
<td>25.03</td>
</tr>
<tr>
<td>pkva</td>
<td>20.90</td>
<td>23.72</td>
<td>25.14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DF</th>
<th>WT</th>
<th>CT</th>
<th>CHMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>pkva</td>
<td>22.06</td>
<td>24.26</td>
<td>25.40</td>
</tr>
<tr>
<td>haar</td>
<td>21.92</td>
<td>23.47</td>
<td>25.09</td>
</tr>
<tr>
<td>5/3</td>
<td>22.02</td>
<td>23.94</td>
<td>24.21</td>
</tr>
<tr>
<td>9/7</td>
<td>21.95</td>
<td>24.29</td>
<td>25.05</td>
</tr>
</tbody>
</table>

The filters we mentioned above have the characteristic of orthogonal, but just some of them have the characteristic of biorthogonal. The linear phase characteristic is very important in image processing, if the image data input symmetrical, the linear phase will keep the outputs coefficients symmetrical. The linear phase characteristic solved the edge effect and the coefficient development question. The general orthogonal wavelet does not have the linear characteristic. Biorthogonal wavelet has the linear phase, so it gains good image denoising result. So the filter we will construct needs to be biorthogonal at least.

4. Filter improvement

From the introduction above, we find that different filters influence the denoising result. To choose a good filter is very important in image denoising. So we want to construct a new filter which is better than 9/7 and has the characteristic of human vision. In this section we will build a new filter model and prove its feasibility.

4.1 Multi-resolutions analysis

By the multi-resolutions analysis definition, the primary function satisfies the double scale equation:
\[
\phi(t) = \sum_k h_k \phi(2t - k)
\]

Let \( \psi = V/V', \phi(t) \) is basic function of \( \psi_j \) spatial and \( \phi(t) \) function also have double scale equation:

\[
\phi(t) = \sum_k h_k \phi(2t - k)
\]

\( \phi(t) \) and \( \phi(t) \) are separately called the scale function and the wavelet function.

**Definition 1:** if the scale function and the scale function satisfy:

\[
(\tilde{\phi}(t), \phi(t - k)) = \delta_{0,k}
\]

\( \phi(t) \) and \( \tilde{\phi}(t) \) are dual scale function.

Under the double scale resolution analysis frame, the scale function correspondence double scale equation is:

\[
\tilde{\phi}(t) = \sum_k \tilde{h}_k \phi(2t - k)
\]

**Definition 2:** if \( \tilde{\phi}(t), \tilde{\phi}(t), \phi(t) \) and \( \phi(t) \) satisfy:

\[
\langle \tilde{\phi}(t), \phi(t - k) \rangle = 0 \quad \langle \phi(t), \phi(t - k) \rangle = \langle \phi(t), \phi(t - k) \rangle = \delta_{0,k}
\]

Then \( \tilde{\phi}(t) \) and \( \phi(t) \), \( \tilde{\phi}(t) \) and \( \phi(t) \) orthogonal each other, the wavelet satisfies the above condition named biorthogonal the wavelet.

### 4.2 Biorthogonal wavelet

Supposes \( H_0(\xi), H_1(\xi), G_0(\xi) \) and \( G_1(\xi) \) separately on behalf of the decomposition of low pass, decomposition of high pass, the synthesis low pass and the synthesis high pass. If they satisfy biorthogonal formula (6):

\[
H_0(\xi) G_0(\xi) + H_1(\xi + \pi) G_1(\xi + \pi) = 1
\]

Then will say they can constitute group of biorthogonal wavelets filters. Simultaneously, its precise construction conditions formula (7):

\[
H_0(\xi) G_0(\xi) + H_1(\xi + \pi) G_1(\xi + \pi) = 1 \quad H_0(\xi) G_0(\xi + \pi) + H_1(\xi) G_1(\xi + \pi) = 0
\]

are naturally satisfied. High pass filter according to the formula is

\[
H_1(\xi) = \exp(-j\xi) G_0(\xi + \pi) \quad G_1(\xi) = \exp(-j\xi) H_0(\xi + \pi)
\]

### 4.3 Human vision biorthogonal wavelet

Image information is obtained by human vision, so construct a filter that can perfectly describe human vision is necessary. Mannos and Sarison [8] have built a model near human vision function:

\[
A(\xi) = 2.6(0.192 + 0.114\xi) \exp[-(0.114\xi)^{1.1}]
\]

The characteristics of human vision and human psychology show that the huge range of changes and abundant detail areas are easy to attract human eyes. But the smoothness change areas are not so attractive. So according to the human vision function, we built tight biorthogonal wavelet ‘9/7’ (‘V9/7’), the coefficient of transformation perfectly describe person’s visual characteristic.

![Scale function and wavelet function base on V9/7 wavelet](image)
The decomposition and the construction of the scale function and the wavelet function from Fig.1 are extremely similar. In experimental process, there are some kinds of the orthogonal wavelets and linear biorthogonal wavelets, we separated biorthogonal wavelet and orthogonal wavelet on the comparison of image denoising result, selected the best pyramid filter Daubechies ‘9/7’ orthogonal wavelet which already confirmed above and the ‘V9/7’ biorthogonal wavelet which has visual characteristic. Fig.1 is ‘V9/7’ scale function and the wavelet function.

5. Numerical Experiment

In this section, we compared the original Contourlet transform (CT) with those from the new Contourlet transform (CT-V9/7) proposed in this paper. We can see from Fig.2. The original Contourlet transform decomposed images by Contourlet using ‘9/7’ filter bank were shown by Fig.2 (b). New Contourlet transform decomposed images by using ‘V9/7’ filter bank were shown in Fig.2 (c).

From each direction of the decomposed image we found that the images of fig.2 (b) cause pseudo-Gibbs phenomena around contours while images of fig.2 (c) were refine by well-adapted sketches along the contours. So we can see that new Contourlet transform has better performance than the original; especially keep the margin in good vision.

5.1 Optical image denoising

We apply two kinds of filters to the optical image denosing. Table 2 shows the PSNR of the denoised images by using different algorithms, such as Contourlet (CT), new Contourlet transform (CT-V9/7), Contourlet HMT (CHMT), new Contourlet transform HMT (CHMT-V9/7).

From the simulation results above, we find that the results of ‘V9/7’ filter in image denoising better than orthogonal ‘9/7’ filter. ‘V9/7’ is an improved filter, especially used in CHMT transform. The CT-V9/7 image denoising improved inconspicuous. But CHMT-V9/7 algorithm shows better performance while the PSNR of denoising image increased 0.6-1.2dB.

'V9/7' has the linear phase and the better visual characteristic, it remedies the flaw of CHMT in the visual effect, makes denoising image shown fig.3 better than the filter '9/7'.
Simultaneously, Tight filter has a stronger partial performance, enhances the image detail capture ability, and maintains image edge integrally.

5.2 Infrared image denoising

We have already applied the filters to the optical images and proved its superiority. In this section we will apply it to the infrared images to see if it has the same superiority. We used the infrared images Bridge and Lake to carry on the simulation. The results were shown in Table 3.

Table 3. The comparison of two kinds of filters in infrared image denoising

<table>
<thead>
<tr>
<th>σ</th>
<th>Bridge</th>
<th></th>
<th></th>
<th></th>
<th>Lake</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>

Table 3 shows the PSNR of the infrared images by using different algorithms. Although CT-V9/7 has small improvement, but greater improvement is achieved by CHMT-V9/7. Due to the improvement of the filter, the reconstructed image from CHMT-V9/7 is visually much better than the one from CHMT.

6. Conclusion

This article analyzed pyramid filter and the directional filter in the multi-criteria geometry analysis transformation, to compare the different combination of filters, we proposed the tight characteristic and conform to the human vision filter, used the different type of noised image in image denoising, the 'V9/7' filter that this article proposed not only maintains the effect of original filter in other algorithms in image denoising, but also makes the CHMT-V9/7 algorithm denoising result surpass the result of original filter.

7. Acknowledgments

This study was supported by research funds from the National Natural Science Foundation of China (NO.10172043), the Aeronautics Science Foundation of China (NO. 05G52047), the Specialized Research Fund for the Doctoral Program of Higher Education of China (NO.20040287012), and International Science and Technology Cooperation Program (NO.BZ2008060).

References