基于Mallat和À Trous小波变换的多光谱与SAR影像融合

Multi-spectral and SAR Images Fusion via Mallat and À Trous Wavelet Transform

韩念龙  胡金星  柳想

摘要  多光谱和SAR影像包含的信息具有不同特征。多光谱影像包含着大量的光谱信息，而SAR影像则具有丰富的纹理信息，如建筑物，路网等。基于小波变换的SAR和多光谱TM影像融合保证融合图像包含更多空间细节信息：不仅保留TM影像的光谱信息以避免信息损失，同时也突出了SAR影像的纹理信息。在本研究中，分别利用Mallat和À trous小波算法进行SAR和TM图像融合。在图像融合之前，SAR和TM图像进行了地理坐标配准。在小波分解中，利用信息熵统计的方法来确定小波分解的尺度。通过分析融合图像的信息熵，方差，平均梯度和相关系数，评价两种算法的融合效果。结果表明，通过基于小波变换的SAR与TM图像融合，融合后的图像在光谱和纹理信息都得以加强，而À trous小波变换在图像融合中具有较好的效果。

关键词  SAR和多光谱图像融合；Mallat；À Trous

ABSTRACT  The information which is contained in the multi-spectral and SAR images have different characteristic. Multi-spectral images contain a great deal of spectral information, whereas SAR images contain rich texture information, such as buildings and road network. SAR and TM images fusion based on the wavelet transform ensure the fusion image showing more spatial detail, not only conserving the spectral information of the multi-spectral images and reducing the distortions as well, but also highlighting the texture information of the SAR image. In this paper, the wavelet transform-based image fusion methods by using SAR and TM multi-spectral images are implemented by Mallat and à trous algorithms separately. Before the image fusion, both of the SAR and TM images have to be geographic coordinate registered in order to they having the same pixel size. In wavelet decomposition, the decomposition level is determined by statistical of entropy value. According to SAR and TM image fusion based on wavelet transform, it can be seen that the fusion image is greatly improved and both of spectral and textural information are enhanced. The value of entropy, variance, average gradient and correlation coefficients of the fusion image are analyzed for two different algorithms evaluation. By analyzing the results, It can be concluded that the image fusion by à trous wavelet transform has a good effect in experiment.

KEYWORDS  Sar And Multi-Spectral Image Fusion；Mallat Algorithm；À Trous Algorithm

1 Introduction

Multi-sensor images fusion is one of most complex work in that the characteristic of images and mechanism of sensors are different. Multi-spectral image is based on spectral reflectance characteristics of land cover types and contain a great deal of spectral information, whereas reflectivity of SAR image mainly depends on characteristics of the surface target and the incidence angle of the illuminating electromagnetic radiation [1]. Moreover, SAR image contains rich texture information, such as point targets, buildings, road network and so on. Although it is a challenging task to realize the multi-sensor images fusion, the fusion of SAR and multi-spectral images may contribute to a better improving of image classification and display, not only different objects in images can easily identified complex morphological structure such as urban areas, heterogeneous forested areas and agricultural areas [2], but also benefit to facilitate visual and image interpretation.

There are some image fusion methods have been performed for SAR and multi-spectral image fusion. Color-based image fusion algorithms such as IHS (Intensity, Hue, and Saturation) and Brovey methods obtain the missing spatial detail information from intensity image calculated between the lower spatial resolution multi-spectral image and the high spatial resolution SAR image. Then, the determined spatial detail difference is injected into the multi-spectral image to enhance its spatial resolution [3]. The principal component analysis (PCA) image fusion method is
based on the statistical principle. It transfers the spatial detail from the high spatial resolution image using the statistical properties of the high spatial resolution and the multi-spectral images \[9]. Those image merging methods mentioned above do not take into account the contextual spatial information, and do not make use of the complementary characteristics of multi-spectral and SAR data \([5]\). Those methods, which usually called “component substitution” methods \([6]\) is the high distortion of the original spectral information \([7]\).

The wavelet transform method used in this paper usually is described as a multi-resolution decomposition \([8]\). It can be performed in two steps. First, replacing some wavelet coefficients of the multi-spectral image by the corresponding coefficients of the high resolution image(SAR), then adding high-resolution coefficients to the multi-spectral data \([8]\). The wavelet transform is based on the orthogonal decomposition of the image onto a wavelet basis in order to avoid a redundancy of information in the pyramid at each level of resolution, the high and low frequency components of the input image can be separated via high-pass and low-pass filters. Thus, the image fusion with the wavelet multi-resolution analysis can avoid information distortion, ensure better quality and showing more spatial detail. Therefore, comparing with other methods such as IHS, Brovey and PCA, the wavelet transform method has better performance in image fusion. Thus, the SAR and TM image fusion is performed by the Mallat and à trous wavelet transform algorithms in this paper separately, and the advantages and disadvantages of two wavelet algorithms are analyzed in detail.

The remainder of the paper is organized as follows. An overview theory of Mallat and à trous wavelet transform algorithm is given separately in Section II. In Section III, the process of experiment of SAR and TM images fusion are described and performed, then the results of image fusion are analyzed and discussed. Finally, conclusions are drawn in Section IV.

2 the Principles of Mallat and À Trou Algoritims

Some statements are on the usage of the two following sub-sections. Section A describes the theory of Mallat wavelet transform algorithm and section B gives the principles of à trous algorithm.

A. The Mallat’s Algorithm \([10]\)

We assume that \(f(x,y)\) is an image with \(M \times N\) pixels, where \(M\) and \(N\) denotes number of rows and columns respectively. The wavelet decomposition algorithm takes places along rows and columns with low-pass \((l)\) and high-pass \((h)\) filters which are associated with scaling function and wavelet function respectively, then four new sub images are obtained with a size of \((M/2, N/2)\), and the sub image \(f_{LL}^{j}(x,y)\) is called approximation image, whereas \(f_{LH}^{j}(x,y), f_{HL}^{j}(x,y), f_{HH}^{j}(x,y)\) are called horizontal, vertical and diagonal detail images which contain high frequency parts of the image \([11]\).

If the original image \(f(x,y)\) is decomposed at \(N\) level by using Mallat’s algorithm, there will finally generate \(3 \times N + 1\) different sub images, which include \(3 \times N\) high frequency sub images and one low frequency sub image \(f_{LL}^{N}(x,y)\). The wavelet decomposition at different level will affect the result of image fusion finally. Figure 1 shows three level wavelet decomposition using Mallat’s Algorithm.

![Figure 1. Three level wavelet decomposition using Mallat algorithm](image1)

The reconstruction of the image \(f'(x,y)\) can be obtained through inverse wavelet transform using \(L_L^j(x,y)\) approximation, \(L_H^j(x,y), V_H^j(x,y)\) and \(D_H^j(x,y)\) which indicate horizontal, vertical and diagonal detail coefficients respectively. The process of image wavelet decomposition and reconstruction of Mallat’s algorithm is presented in figure 2. \(\uparrow\) and \(\downarrow\) denotes synthesis filters, and they can obtained from \(i(n) = h(n-\downarrow), h(n) = h(n-\uparrow)\), where \(\uparrow\) and \(\downarrow\) are upsampling and downsampling respectively.

![Figure 2. (a)The Mallat’s wavelet decomposition (b) The Mallat’s wavelet reconstruction](image2)
B. À Trous Algorithm

Comparing to the Mallat’s algorithm, the “à trous” algorithm is easy to program, and the most important characteristic of this algorithm is invariance when transforming. The “à trous” algorithm produces a single wavelet coefficient plane at each decomposition level. It allows the separation low-pass frequency (approximation image) from high-pass frequency (wavelet coefficients).

The original image \( C_0(x, y) \) can be expressed as the sum of wavelet planes and its last approximation image \( C_p(x, y) \)

\[
C_0(x, y) = C_p(x, y) + \sum_{j=1}^{p} w_j(x, y)
\]  

(1)

Where \( w_j(x,y) \) is the amplitude of the wavelet coefficient and \( j = 1...p \). \( j \) is the scale index and \( p \) is the number of wavelet coefficient planes \(^{[12,13]}\).

3 Experiments and Results

An example of image fusion performed by Mallat and à trous wavelet algorithms will be given in this section. The original images of TM and SAR are obtained from Landsat and ERS-2 SAR data separately. The resolution of SAR image is about 2 times higher than TM multi-spectral image, and the size of both images is 400*400 pixels. Geometric coregistration must be done between SAR and TM multi-spectral images before fusion of multi-sensor data. SAR image is registered geometrically onto the TM multi-spectral image and all of datasets include the same geographical areas and have the same pixel size. The nearest neighbor resampling method is used to avoid spectral distortion by interpolation. Furthermore, because the images are selected from different sensors, the histogram matching needs to be done in order to make both images having the consistent hue. Then, images fusion can be proceed.

A. The Main Process of Image Fusion

The main steps of wavelet transform-based image fusion are described as follows and shown in the figure 3.

- **IHS transform.** The TM multi-spectral image need to be performed IHS transform in order to get better quality of image fusion. The three bands of multi-spectral image are transformed into the IHS space for further fusion work.

- **Wavelet Decomposition.** Wavelet decomposition is performed on TM image which has been transformed into HIS space and SAR image. The entropy is calculated at each wavelet decomposition level and the statistical analysis method is used to determine the best level of wavelet decomposition.

- **Image Fusion.** In image fusion steps, a 3x3 window is used to select image fusion coefficients. The wavelet decomposition coefficients which have larger variance in the 3x3 window will be selected as the fused image coefficients.

- **Wavelet reconstruction.** The wavelet reconstruction is called inverse discrete wavelet transform also. the process of wavelet reconstruction by Mallat algorithm can be seen in the figure2 (b), and the reconstruction of à trous algorithm can be performed by the formula (1).

- **RGB transform.** In this step, the reconstruction image is transformed into RGB space.

Through the steps mentioned above, the wavelet transform-based fused image can be obtained.

B. Results and Analysis

![image fusion by Mallat's and à trous algorithms](image-url)
Figure 4 shows SAR and TM fused image which are implemented by Mallat and à trous wavelet transform algorithm. It can be seen from the figure, comparing to Mallat’s wavelet transform, and the image fusion by à trous algorithm shows more details about roads and buildings. In order to compare the fusion effect by means of Mallat and à trous wavelet, some image parameters are chosen including Entropy, average gradient and standard deviation as evaluation criteria for both wavelet transform algorithms [14]. From table 1, it is clear that the entropy, mean gradient and standard deviation of fused image via à trous wavelet transform are all higher than the results of Mallat’s. That means the à trous algorithm integrates more information and details into the fused image than the Mallat’s algorithm.

<table>
<thead>
<tr>
<th>Wavelet Algorithm</th>
<th>Entropy</th>
<th>Mean gradient</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallat’s</td>
<td>5.4592</td>
<td>1.0306</td>
<td>18.351</td>
</tr>
<tr>
<td>à trous</td>
<td>5.6876</td>
<td>2.4437</td>
<td>18.796</td>
</tr>
</tbody>
</table>

Figure 5 shows the entropy of fused image via Mallat and à trous algorithms in different wavelet decomposition level separately, and it can be seen that the entropy of Mallat’s algorithm is lower than à trous algorithm at different decomposition levels, the entropy of Mallat’s algorithm have little relationship with the decomposition level in this experiment. Furthermore, the best wavelet decomposition level of Mallat’s algorithm is two, whereas the best decomposition level is one in à trous algorithm.

![Entropy comparison](image)

Figure 5. The entropy of Mallat’s and à trous algorithms in different wavelet decomposition level

4 Conclusion

In this paper, the Mallat’s and à trous wavelet transform algorithms are implemented with the TM and SAR image fusion. Statistics method is used to determine the best wavelet decomposition level, and criteria-based method with windows is used to choose fusion coefficient in image fusion step. As a conclusion, both of the proposed wavelet algorithms can satisfy the image fusion requirement basically and greatly improve the image’s vision and quality. At the same time, the evaluation factors such as entropy, mean gradient and standard deviation are used to analyze the quality of the fusion images with two proposed algorithms. The results show that all the value of the evaluation factors implemented by à trous algorithm are all higher than the Mallat’s. It means that the effects of SAR and TM image fusion by a trous wavelet transform is better than Mallat’s wavelet transform. Moreover, it will provide a reliable basis for target recognition, information extraction and improve terrain classification accuracy.

References


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