GeoEye Image Fusion Vegetation Information Extraction Based on Blue Noise Measurement Texture

Luo Qiu 1,*, Qiming Xiong 2, Yao Liu 3 and Gui Zhang 2,*

1 School of Geosciences and Info-Physics, Central South University, China
2 Central South University of Forestry and Technology, China
3 Computational Geosciences Research Center, Central South University, China

Corresponding authors’ e-mail: 34489492@qq.com (LQ); 595772457@qq.com (GZ)

Abstract. Vegetation high-resolution image segmentation is an important kind of target, while how to fuse image by using spatial and spectral information of GeoEye image, and make effective determination of the scale of vegetation texture segmentation is an important topic. This paper presents an algorithm of GeoEye image fusion vegetation information extraction based on blue noise measurement texture, which the vegetation information spectral response is calculated based on fast Fourier transform, in order to obtain the texture gray scale distribution of vegetation information, thus realizing accurate extraction of vegetation information. The simulation result got by the algorithm shows the deviation between NDVI index and original value index is below 0.05, which is obviously better than those obtained with the two comparison fusion algorithms of PCA transform (smaller than 0.4) and Brovey (smaller than 0.25), and provides the best parameter combination form [120,0.34,0.48]. Hence, it is an effective algorithm for high accuracy GeoEye image vegetation information acquisition.

1. Introduction
Vegetation is a key factor in biogeochemical cycle related to human survival, and is treated as a significant characteristic variable in ecohydrological research [1] – [3]. There are two methods available for vegetation information survey, i.e. conventional site survey and remote sensing survey based on remote sensing images and technologies [4] – [7]. Conventional site survey allows accurate and comprehensive learning of vegetation information in the region. However, such method requires a lot of manpower, material resources and financial resources, thus it is rarely used now. The remote sensing survey can realize vegetation information extraction in a simple manner, while the extraction accuracy and spatial resolution of this method are sometimes relatively low and fail to meet the accuracy required for research. Along with the development of remote sensing technology, remote sensing is developed toward the trend of high spatial resolution, high time resolution, high spectral resolution, multiple platforms, multiple angles and multiple sensors, thus laying a good foundation for accurate vegetation information extraction [8] – [9]. Multispectral remote sensing images (e.g. WorldView, GeoEye) can realize meter resolution, and panchromatic band can realize decimeter resolution. Therefore, the hardware resources are sufficient to meet the demand of accurate vegetation information extraction. How to realize accurate vegetation information extraction with the software becomes a hot and important point of research at present [10] – [11].

The object oriented information extraction method has already become the development direction of high resolution remote sensing image information analysis [12]. There are two critical issues existing in the process of information extraction [13] – [15]: (1) in selection of image segmentation algorithm. The shape factor, scale factor, compactness and other indexes will influence feature segmentation of
the polygon, and even the accuracy of vegetation information extraction; (2) establishment of classification rules and feature extraction. For the issues above, the statistics, frequency domain and texture structure analysis method is the main research mode at present, of which, accurate extraction of vegetation texture features is a critical step. Indexes of texture scale, shape, gray scale distribution and others are crucial for image segmentation.

Many scholars of combined texture feature extraction research have raised different algorithms, for example, Mashimbye et al [16] put forward the extraction model of high spectrum remote sensing data soil information; Bie et al [17] put forward the object and image fusion oriented remote sensing image vegetation information feature extraction technology; Cui et al [18] put forward the spectral feature and object oriented vegetation information feature extraction technology; and Li et al [19] put forward the remote sensing image edge mathematical morphology detection method. Although certain effects have been obtained with these algorithms, they have a common problem of low vegetation texture feature extraction accuracy. Hence, in this study, according to the specific scale signal frequency feature presented by different vegetation information, an image fusion vegetation information extraction method based on blue noise theory measurement texture is put forward on the basis of GeoEye data, for realizing fast and accurate extraction of vegetation feature information for the detected region [20] – [22].

2. Site description
GeoEye is a well-known spatial geographic information supplier at present, which can provide better regional mapping and monitoring services for the users [23] – [24]. The image data selected in this article comes from GeoEye-1 satellite of the USA, which is equipped with a CCD high resolution camera, and allows resolution above 0.41m for the panchromatic band and 1.65m for multispectral band. These images were taken at 10:30 am on August 5th, 2013. The region under research is Tianlaochi Catchment in the upstream of the Heihe River. It is located in the middle section of Qilian Mountain, with geographic coordinates of 38°23’56”~38°26’47”, 99°53’57”~99°57’10”E surveyed. The total area of this region is about 12.8 Km².
Tianlaochi Catchment is at the elevation of 2,700~4,440m, with the landform rising from the west to the east. In this region, the annual mean temperature is 5°C, the peak monthly mean temperature 20°C, the minimum monthly mean temperature -18°C, the annual mean rainfall 433mm and the annual mean water evaporation 1,080mm. The main terrestrial objects in this region include: sabina przewalskii, picea crassifolia, bushwoods, steppes, alpine meadow, bare rocks, rivers and so on. Sabina przewalskii and Picea crassifolia cover the largest area in this region. But they are distributed at obviously different locations, i.e. Sabina przewalskii mainly on the sunny slope of Qilian Mountain, and Picea crassifolia mainly on the shady slope of Qilian Mountain. GeoEye image of this region is as shown in Figure 1.

![Figure 1. GeoEye image of study area.](image)

3. Blue noise characteristics of GeoEye image vegetation texture
3.1. Vegetation texture analysis

Texture analysis can be divided into microcosmic and macroscopical aspects generally, of which, the former one is mainly related to texture comparison and set shape, and the later one mainly involves texture period, spatial scale, direction and so on. In the process of high resolution GeoEye image vegetation information extraction, the spatial scale of vegetation shall be distinguished macroscopically, so as to improve the recognition efficiency. There are sabina przewalskii, picea crassifolia, grasslands, meadow and others distributed in the research region. They differ from each other in color tones, crown characteristics, plant locations, contrast and so on. In the microscopical aspect, the vegetation texture presents obvious cluster shape structure, with the contrast at the center obviously different from that at the surrounding part. Additionally, the different contrast shapes presented are related to the plant types.

When GeoEye image is shrunk to a certain scale, the crown shadows of tall trees and highlight regions will be shrunk into single pixel points and present high frequency characteristics. These high frequency, aperiodicity and random features of vegetation texture coincide with the features of blue noise. The blue noise is a type of aperiodic, low frequency random signal without obvious peak in the frequency spectrum. With a limited bandwidth, the power spectrum density is in proportion to the frequency index. In computer graphics, the blue noise is usually used for composition of halftone dithering images, which agree with the visual features of human beings. Therefore, GeoEye image processing mode based on blue noise theory is a new method for vegetation information extraction.

3.2. Vegetation texture region selection of GeoEye images

In order to further increase the detection efficiency, it is necessary to select the blue noise feature regions in a reasonable manner. GeoEye image is equally divided into regions firstly, and each region is scanned for fast selection of the suitable regions. The gray scale and color tone distribution features of the region are utilized for realization of forest region judgment in this research.

In the aspect of color tone distribution features, the vegetation is in green color generally. The deciduous vegetation shows other colors in winter, with the crown shapes varying as well. The algorithm shall be determined based on different conditions. The brightness interference can be eliminated effectively since HSV tonal space feature is unrelated to the brightness. The texture region of GeoEye image is mapped from RGB space to HSV tonal space, and H value in the region is counted and averaged. For HSV tone model, the optimal green color H value approaches 120.

As for the gray scale distribution, the typical vegetation in GeoEye image usually presents regional distribution. The crowns of sabina przewalskii, picea crassifolia and other tall plants present areatus distribution microcosmicly with obvious contrast. Such gray scale distribution is repeated and shows low gray scale feature, and the gray scale probability density presents normal distribution feature. Assuming that the data vector in a region of GeoEye image is \( X \), the data capacity is \( n \), the third moment of \( X \) is \( S \) and the fourth moment is \( K \), then \( J_B = \text{Jarque – Bera} \) detection formula can be expressed as:

\[
J_B = \frac{n}{6} \left[ S^2 + \frac{(K-3)^2}{4} \right]
\]  

(1)

Where, in case of normal distribution of gray scale, the third moment of vector \( X \) is 0 and the fourth moment is 3, \( J_B = 0 \). The results of detection formula above Jarque – Bera are normalized, and the region is distinguished using the average color tone value and normal distribution, in order to select the blue noise feature image region.

4. Image fusion algorithm based on feature classification

4.1. Algorithm description

Equally divide the GeoEye image into \( N \) ones, and screen the gray scale and color tone of each divided region, so as to obtain the reasonable region for enhanced contrast adaptation processing. At the same time, work out the blue noise feature of image using the iterative algorithm for the region obtained. The iterative algorithm process mainly includes the following steps: 1. geometric transformation for size reduction of the region, 2. fast Fourier transform (FFT) spectral response of the
region, 3. Blue noise feature extraction. Perform vegetation information feature calculation for the feature region in GeoEye image, and work out the vegetation texture size using the blue noise feature region size. The algorithm process is as shown in Figure 2.

![Figure 2. Texture feature extraction process.](image)

When the region selected in GeoEye image is oversized, the vegetation texture of GeoEye image presents obvious micromosaic structure feature, and the vegetation texture feature reflected presents large texture size and smooth gray scale transition. On the aspect of frequency feature, it presents strong low frequency signal and pink noise or red noise feature. When the vegetation texture size of GeoEye image is reduced to the pixel level, the micromosaic low frequency signal will disappear and the high frequency random oscillation feature becomes more obvious. Similar to the blue noise feature, there is no low frequency signal, and the high frequency signal is in proportion to the frequency.

4.2. GeoEye blue noise feature extraction

During pre-processing, smoothing and frequency shifting is required for the region spectrum obtained via fast Fourier transform. For effective judgment of direction, it is necessary to obtain the energy spectrum of N directions at equal angle interval with the origin as the center. The calculation formula is $E_{i1}, E_{i2}, \cdots, E_{ik}$. Then, the total energy $P$ of direction $i$ can be worked out, i.e.:

$$P_i = \sum_{j=1}^{K'} E_{ij}$$  \hspace{1cm} (2)

Where, $K'$ is the total energy spectrum in a direction, and $j$ is the temporary counting variable. The energy variance of different directions is expressed as:

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (p_i - p_{\mu})^2}$$  \hspace{1cm} (3)

Where, $p_i$ is the random energy value in direction of $i$, and $p_{\mu}$ is the expected value of $p_i$. If $\sigma = 0$, it indicates that GeoEye blue noise feature has no directionality.

Assuming that the directionality of GeoEye blue noise feature is weak, the energy spectrum in N directions is combined to obtain the overall one-dimensional energy spectrum $E_{i1}, E_{i2}, \cdots, E_{ik}$, and $p_r$ is the sum of energies above, the calculation formula of the third moment is:

$$S = 1/P_r \sum_{x=1}^{K'} (f_x - f_m)E_x$$  \hspace{1cm} (4)

Where, $f_x$ is the frequency, $f_m$ is the center frequency, and $E_x$ is the sum of frequency spectrum in N direction. Under ideal conditions, when $k(x) > 0$ in the function, the calculation formula of $k(x)$ is:

$$k(x) = E(x)/f(x)$$  \hspace{1cm} (5)
Work out the variance of $k(x)$ defined in the formula above. The closer is the value to 0, the stronger is the feature of energy spectrum density proportion and frequency. In conclusion, the condition for judging the blue noise feature of GeoEye region is: $\sigma = 0, S > 0$, and the variance of $k(x)$ close to 0.

4.3. Calculation of texture size and gray scale distribution
With the blue noise feature acquired with the algorithm above, calculate the scale of vegetation crown texture based on the sizes of this region and the original region, in order to obtain the pixel quantity of vegetation crown. Since the shadow and highlight part of texture occupy a pixel point respectively, the texture scale calculation formula is as below:

$$wc = 2 \times \frac{c_{\text{original}}}{c_{\text{current}}}$$  \hspace{1cm} (6)

Where, $wc$ is the texture size, $c_{\text{original}}$ is the original region size and $c_{\text{current}}$ the current region size.

Gray scale distribution calculation is the foundation of morphological segmentation design for GeoEye image. Repeated appearance of vegetation crown texture can form obvious normal distribution form. The gray scale distribution form of GeoEye image can be calculated based on the histogram distribution form of original gray scale, with the contrast, average value and peak value of gray scale involved. The calculation formula of gray scale contrast is:

$$DB = \frac{1}{M} \sum_{i=1}^{M} \delta(i,j)^2 p_g(i,j)$$  \hspace{1cm} (7)

Where, $p_g(i,j)$ is the pixel distribution probability, $\delta(i,j) = |i - j|$ is the adjacent gray scale difference between pixels, and $M$ is the total number of adjacent pixel relation.

5. Experimental parameter selection and comparison analysis

5.1. Parameter selection of fusion algorithm
Define the algorithm parameter index: extract the quality rate (QR), under segmentation rate (UR), over segmentation rate (OR) and distance (ED). The calculation formula is:

$$QR = 1 - \frac{\sum |r_1 \cap s_k|}{\sum |r_1 \cup s_k|}$$
$$OR = \frac{\sum |s_k - r_1|}{\sum r_1}$$
$$UR = \frac{\sum |r_1 - s_k|}{\sum r_1}$$
$$ED = \sqrt{(OR^2 + UR^2)/2}$$  \hspace{1cm} (8)

Where, $r_1$ is a polygon of blue noise region, $s_k$ is the polygon of vegetation segmentation region, $|r_1 \cap s_k|$, $|s_k - r_1|$ and $|r_1 - s_k|$ represent the overlapped, under segmentation and over segmentation part respectively.

GeoEye remote sensing image 1 is taken as an example for explanation, with the reference polygon of sabina przewalskii, picea crassifolia, alpine meadow, steppes, bushwoods, rivers, bare rocks and other landforms formed. Six corresponding reference polygons are formed for each type of landform. With \{78, 103, 122, 137, 158\} as the segmentation scale, and compactness and shape factor of \{0.11, 0.23, 0.34, 0.48, 0.52, 0.65, 0.78, 0.86, 0.97\}, there are $5 \times 9 \times 9$ types of parameter combination. The parameter combination and evaluation index value are as shown in Table 1 and Table 2.

According to Table 1 and Table 2, among the segmentation parameter combinations of the vegetation types, better effects can be obtained with large scale segmentation for area distribution feature of abina przewalskii, picea crassifolia, alpine meadow, bushwoods and steppes. At the same time, for various vegetation types, the optimal segmentation scale is 120, the optimal shape factor is 0.34, and the optimal compactness 0.48. Hence, the parameter combination adopted in this article is [120, 0.34, 0.48].
Table 1. QR sort parameter combination.

| Terrestrial object type | QR sort | Segmentation scale | Shape factor | Compactness |
|-------------------------|---------|--------------------|--------------|-------------|
| Picea crassifolia       | 0.153   | 100                | 0.34         | 0.65        |
| Abina przewalskii       | 0.132   | 102                | 0.23         | 0.52        |
| Bushwoods               | 0.124   | 140                | 0.48         | 0.86        |
| Alpine meadow           | 0.157   | 140                | 0.34         | 0.48        |
| Steppes                 | 0.146   | 120                | 0.34         | 0.34        |
| Rivers                  | 0.079   | 80                 | 0.52         | 0.34        |

Table 2. ED sort parameter combination.

| Terrestrial object type | ED sort | Segmentation scale | Shape factor | Compactness |
|-------------------------|---------|--------------------|--------------|-------------|
| Picea crassifolia       | 0.563   | 120                | 0.23         | 0.48        |
| Abina przewalskii       | 0.479   | 140                | 0.23         | 0.65        |
| Bushwoods               | 0.316   | 120                | 0.48         | 0.52        |
| Alpine meadow           | 0.608   | 100                | 0.11         | 0.86        |
| Steppes                 | 0.491   | 120                | 0.34         | 0.48        |
| Rivers                  | 0.238   | 80                 | 0.48         | 0.23        |

5.2. Comparative analysis of fusion result

The remote sensing fusion algorithm influences the fusion effect largely, and is liable to cause data distortion. The commonly used centralized image fusion algorithm is used herein for comparison experiment with GeoEye remote sensing image in Figure 1 and a standard universal remote sensing image. Experiment hardware configuration: i7-990X 3.73GHz, 4G ddr3-1600. The comparison algorithms are: main component analysis algorithm (PCA transform), Brovey fusion algorithm and FFBN algorithm discussed herein. The experiment comparison result is as shown in Figure 3. Fusion comparison of two GeoEye remote sensing images, i.e. RGB combined image and gray scale image, is provided. The comparison result shows that, the fusion effect of FFBN algorithm discussed herein is better than those of PCA transform and Brovey fusion algorithms visually.

![Figure 3](image1.jpg)

(a) GeoEye remote sensing image 1. (b) GeoEye remote sensing image 2.

Figure 3. Comparison between two images of GeoEye remote sensing image.

The terrestrial object information can be reflected by defining the vegetation index normalization index after vegetation information feature fusion extraction. The calculation formula is:

\[
\text{NDVI} = \frac{(\rho_{NIR} - \rho_R)}{(\rho_{NIR} + \rho_R)}
\]  

(9)
Where, $\rho_{\text{NIR}}$ is infrared radiation parameter, and $\rho_{\text{R}}$ is red light radiation. Figure 4 shows comparison of NDVI indexes of many algorithms. According to NDVI index comparison in Figure 4, the difference between the NDVI indexes of FFBN algorithm and the original value index is smaller than 0.05, better than that obtained with PCA transform (smaller than 0.4) or Brovey (0.25) fusion algorithms, i.e. the NDVI index of FFBN algorithm is the closest to the original value.

\[ \text{Figure 4. NDVI index comparison.} \]

### 6. Conclusion

What makes high-resolution remote sensing image different from general natural color images is that the former contains large amount of information, complex relationships and multiple features. Therefore, it is difficult for high-resolution image segmentation to achieve the desired effect by directly using the methods of gray scale segmentation or color image segmentation. The current common technologies of image segmentation are mostly based on texture analysis, and the texture features is the vital step. The consistency of color and gray scale is so poor when extracting the remote sensing image vegetation information, while the texture information is very stable. A new texture describing method based on blue noise measurement texture is discussed herein, which is used to measure texture dimension and gray scale of typical regional vegetation in remote sensing image, thus realized extraction of high resolution GeoEye remote sensing image vegetation information. Effectiveness of the algorithm put forward is verified via experiment and comparison analysis, and experiments for value determination of relevant parameters for the algorithm are given herein, thus providing basis for application expansion of the algorithm.

The measuring result gives support to further texture segmentation of forest vegetation by measuring remote sensing image vegetation information according to blue noise theory. For example, this may involve structure element scale related to texture dimension, and gray scale distribution of structure element related to distribution of texture gray scale when the segmentation makes use of gray scale morphology texture filter method. By measuring remote sensing image texture based on blue noise theory, this paper proves the vegetation texture of remote sensing image has blue noise features in specific spatial scales, which is a reference for processing similar texture of ground feature in remote sensing image. The research will be mainly focused on utility program development, and calculation accuracy and efficiency of the algorithm need to be further optimized, so as to meet the requirements for accuracy and real-time performance in practical applications.

### 7. References

[1] VF Rodriguez-Galiano, M Chica-Olmo, F Abarca-Hernandez 2012 Remote Sensing of Environment 121 93-107.
[2] K Mansour, O Multanga, T Everson 2012 Isprs Journal of Photogrammetry & Remote Sensing 70 56-65.
[3] XL Gao, XQ Wang 2008 Resources Science 30 153-8.
[4] Liu C, Qiumin L 2010 Research on plant information identification, extraction and change monitoring based on multi-source remote sensing data Geoscience and Remote Sensing
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