Extraction of raft cultivation of remotely sensed high-spatial-resolution images based on LBV and wavelet transforms

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Abstract. A method to extract information on raft cultivation based on the LBV (The general radiance level L, visible-infrared radiation balance B, and band radiance variation vector V) transform and wavelet multi-scale decomposition was proposed. This paper selects the spectral information of typical objects and uses regression analysis to solve for the coefficients of regression. The LBV transformation of remotely sensed high-spatial-resolution imagery was derived according to the spatial characteristics of the object space, color space, and LBV variable space to obtain the B band that can be used to identify maritime targets. Multi-scale wavelet decomposition was then used to calculate the eigenvalues of the components of each sub-image by using different windows to analyze the texture features of the maritime objects, and to explore the rules of texture extraction of raft cultivation from high-spatial-resolution images. Experiments on remotely sensed ZY-3 images from Liandao Island show the following: (1) compared with the original image, the LBV-transformed image was clearer and finer details were visible in it. They helped identify and extract ground objects. (2) The eigenvalues extracted by wavelet decomposition were beneficial for the segmentation of the image. As the dimensionality of the eigenvalue increased, the accuracy of raft cultivation extraction showed an upward trend. (3) The proposed method is applicable to texture feature extraction owing to its clear rules and directionality.

1. Introduction

Marine aquaculture is a method of production that uses shallow seas to raise and breed marine animals and plants. It is an important way for humans to use living marine resources. China’s marine aquaculture has a long history and its scale of breeding has increased year by year. In 2018, the area of marine aquaculture used by it was 2.043 million hectares. While marine aquaculture promotes coastal economic development, it also causes the deterioration of the ecological environment, leading to frequent pests, diseases, and red tides in the breeding areas[1], reduced transparency of water bodies[2], and reduced genetic diversity of the species[3]. Therefore, marine aquaculture has become the focus of marine environmental monitoring. The rapid acquisition of the location, area, and type distribution of
marine aquaculture in China can provide data to support the activities of marine regulatory authorities in China, such as the supervision of the marine aquaculture and the evaluation of the carrying capacity of the ecological environment.

The early monitoring of marine aquaculture mainly employs on-site surveys that incur large workloads and long cycles. With the development of remote sensing technology, remotely sensed images are being widely used for marine aquaculture monitoring. Li extracted the aquaculture area of a lake enclosure using multi-spectral data from the China–Brazil Resource Satellite[4]. This method can be used to accurately extract the area of aquaculture, and has high precision of extraction. Fan used RADASAT-1 data for JiaoZhou Bay in 2001 to explore the feasibility of SAR imagery for marine aquaculture monitoring[5]. The results of extraction intuitively and objectively reproduced the distribution of the culture area. Liu, Ma, and Mcfeeters improved the water body index by the spectral analysis of seawater and the marine target, and extracted information on the area of marine aquaculture by SPOT and ASTER data[6-8]. Chu used Landsat TM images to extract information on the Wakame raft culture based on association rules[9]. Using object-oriented idea, Guan and Xu used e-cognition software to segment images and extract information on the marine aquaculture[10,11].

This paper proposes a method for extracting information on raft cultivation by using the LBV (The general radiance level L, visible-infrared radiation balance B, and band radiance variation vector V) transform and multi-scale wavelet decomposition feature extraction. The LBV transform is a conceptual model of image transformation[12,13]. Different spectral-space remote sensing images have different corresponding LBV transform models. The LBV transform can render the image clearer and reveal abundant details by transforming the spectral values of the ground objects. It has been widely used in satellite image enhancement and subsequent application[14-17]. Wavelet transform can separate detailed information from non-stationary spatial signals at a certain scale, and wavelet coefficients can be regarded as the measure of the texture of the signal at a certain scale. Wavelet texture feature analysis has been applied to methods of classification and target extraction for high-resolution remotely sensed imagery[18-22].

2. Study area and data acquisition
Liandao Island, the largest island in Jiangsu Province and adjacent to Lianyungang across the sea, is located at 34°42–34°45' N and 119°21–119°32' E. It is located in Haizhou Bay, among the eight largest fishing areas in China. It is rich in marine aquatic products, and is full of shellfish and Wakame offshore.

In this paper, ZY-3 satellite data were used as data source. The ZY-3 is the first civilian high-resolution stereo mapping satellite in China. The satellite is equipped with four high-resolution CCD cameras with a panchromatic band spectrum and multi-spectral band. The panchromatic band spectrum ranged from 0.45 to 0.80 μm and its spatial resolution was 2.1 m. The multi-spectral band consisted of four further bands, and their spectral ranges were 0.45–0.52 μm, 0.52–0.59 μm, 0.63–0.69 μm, and 0.77–0.89 μm, and the spatial resolution was 5.8 m. Images of the study area were captured on October 19, 2018.

3. Methods
The general idea of this paper was that based on the preprocessing of high-spatial-resolution images, the B band that could distinguish between the water and targets in it was obtained by LBV transformation. Following this, multi-wavelet decomposition was used to extract the multi-dimensional eigenvectors of the maritime targets, their eigenvalues were used as input parameters, and a support vector machine was used to extract the raft cultivation. Finally, the extracted information was processed by removing isolated points and smoothing the contours. The process of extraction of raft cultivation is shown in Figure 1.
3.1. LBV transformation
The general radiance level $L$, visible-infrared radiation balance $B$, and band radiance variation vector $V$ are important characteristics of feature radiation in remotely sensed images. Of the many types of ground features, the general radiance level of bare land is the highest, the infrared radiation level of water is the weakest, and the radiation of vegetation varies most drastically with the band. Therefore, the $L$ band in the LBV transformation corresponds to bare land, the $B$ band corresponds to water, and the $V$ band corresponds to vegetation.

The formula for ZY-3 remotely sensed images based on the LBV transformation is used to solve for the coefficient of the regression curve by using linear and quadratic regression methods according to the relationship between the estimated spectral value and the true value of typical ground objects in the four bands of ZY-3 multi-spectral images. The values of $L$, $B$, and $V$ were then calculated according to the characteristics of LBV. $L$ is the ordinate of the extreme point of the quadratic regression curve that reflected the general radiance level of the ground object. $B$ was the slope of the liner regression curve that reflected the ratio of visible infrared. $V$ was the residual value between the estimated quadratic regression curve of each band of the multi-spectral image and the true radiation value of the ground object. $V$ was negative such that the greater this negative value was, the denser was the vegetation. The LBV transformation of ZY-3 satellite images is as follows:\[23]:

\[
L = 32.56D_1 - 0.7748D_2 - 5.8714D_3 + 2.2195D_4 \tag{1}
\]

\[
B = 2.1308D_4 + 1.2336D_2 - 0.4112D_3 - 2.9533D_4 \tag{2}
\]

\[
V = -0.726D_1 + 1.363D_2 - 0.792D_3 + 0.1556D_4 \tag{3}
\]

3.2. Wavelet decomposition

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**Figure 1.** Flowchart of extraction of raft cultivation.
The Mallat algorithm can be used to construct orthogonal wavelet bases. According to it, the signal can be decomposed into detail and approximation signals at different scales. In this paper, the wavelet coefficients are calculated by using db4. The scale coefficients ($c_k^j$) and wavelet coefficients ($d_k^j$) of a wavelet transform at scale $j$ are expressed as:

$$c_k^j = \sum_n h(n - 2k)C_n^{j-1} \quad (4)$$

$$d_k^j = \sum_n g(n - 2k)C_n^{j-1} \quad (5)$$

A flowchart of multi-scale wavelet decomposition is shown in Figure 2, where $U$ represents the original images, $g(n)$ represents the scaling function that features low-pass filtering, and $h(n)$ represents the wavelet function that has high-pass filtering.

The multi-scale wavelet decomposition of remotely sensed imagery was filtered and sampled by row or column to obtain four sub-images with low frequency, horizontal detail, vertical detail, and diagonal detail, respectively. The wavelet decomposition of the remotely sensed imagery is shown in Figure 3, where Figure 3 (a) is the original image, (b) is the first-order wavelet decomposition sub-image, (c) is the second-order wavelet decomposition sub-image, and (d) is the third-order wavelet decomposition sub-image.

The eigenvalues of the sub-image obtained by the wavelet transform of the image using sample data as window are represented by entropy, and the sequence of eigenvalues of the sub-images is used as the eigenvector of the sample. The eigenvalues are calculated as follows:

$$EV = -\sum \sum R(i,j) \log_2 R(i,j) \quad (6)$$

$$R(i,j) = \frac{(P(i,j))^2}{\sqrt{\sum P(i,j)^2}} \quad (7)$$

where $P(i,j)$ is the gray value of the sub-images.
4. Results and analysis

4.1. Results of LBV transformation

An image of Liandao Island under LBV transformation was obtained by the relevant formula. To facilitate the subsequent feature extraction and accuracy evaluation, the standard deviation and mean of the LBV image were set to 25 and 128, respectively. Through image band operation, the pixel values of the LBV image were set to between 0 and 255 to satisfy the normal distribution. The LBV transform image of Liandao Island is shown in Figure 4. Figure 4 (a) shows the original remotely sensed image, (b) shows the L band of the LBV transform, (c) is its B band, and (c) is the V band of the LBV transform.

Figure 4 shows that we chose selected the port, river, and forest for comparison. Figure 4(b) shows that the port had the highest spectral value followed by the river and the forest. Figure 4(c) shows that the river had the highest spectral value, the forest had the lowest spectral value, and that of the port...
was between their values. Figure 4(d) shows that the forest had the highest spectral value, the port had the lowest, and the river had a value between theirs. The results of this paper are consistent with theoretical derivations\[23]\. From the perspective of visual effect, details of the image were clearer and colors were richer than in the original image.

4.2. Analysis of wavelet decomposition
Because a large sample window can reduce the number of training samples for the image, leading to the simplification and typing of the sample texture, it cannot reflect the texture characteristics of small objects and produces a size effect of banded edges due to the window. The authors chose window sizes of 16×16, 32×32, and 64×64 for feature decomposition, and analyzed the influence of different window sizes on texture feature extraction.

According to the Mallat pyramid structure, the 16×16 window can be decomposed twice, the 32×32 window three times, and the 64×64 window can be decomposed four times. Each order of wavelet transform can decompose four sub-images and extract four eigenvalues, Then, the 16×16 window can extract eight eigenvalues, the 32×32 window can extract 12 eigenvalues, and the 64×64 window can extract 16 eigenvalues. In this paper, the eigenvalues were used as input parameters, and support vector machines were used to classify the images and extract raft cultivation. Given that the purpose of this paper was to extract the target information of marine aquaculture by using the B value of the LBV transformation, prior to classification, land mask processing was carried out on the image to improve the speed of operation. In this paper, three windows (16×16, 32×32, 64×64) were used to obtain the eigenvalues of the target texture by wavelet decomposition, The results of the three windows are shown in Figure 5. Figure 5(a) shows the reference data extracted from field surveys and visual interpretation based on remote sensing. Figures 5 (b), (c), and (d) show the results of the extraction of information from the 16×16, 32×32, and 64×64 windows, respectively. The accuracy curves of raft cultivation for the three windows are shown in Figure 6. Figures 6 (a), (b), (c) show the accuracies of the information extracted related to raft cultivation for the 16×16, 32×32, and 64×64 windows, respectively.

(a) The reference data

(b) Results from 16×16 window
By comparing (b), (c), and (d) in Figure 5, the boundary of information extraction in (b) was the most elaborate, but features insufficient segmentation and leakage, and its classification accuracy was low. Larger windows could be decomposed with higher orders, and (d) could better reflect the texture of the ground object, but there were banded edges along the boundary.

Figure 6 shows that the classification accuracy of raft cultivation exhibited an overall upward trend with the increasing order of wavelet decomposition. From the single curve, the precision of extraction varied most from L1_4 to L2_5, followed by L2_8 to L3_9 and L3_12 to L4_13, which indicated that the texture information of the low-frequency image was abundant in the wavelet decomposition sub-image, and its texture recognition capability was the highest.

5. Conclusion
In this paper, a method to extract information on the marine aquaculture based on the LBV transform and wavelet multi-scale decomposition was proposed. First, the LBV transform was used to enhance the color contrast and enrich the details of ground objects in the original image. Second, multi-scale wavelet decomposition was used to extract the eigenvalues at different scales. Finally, by using the eigenvalue as input parameter, a support vector machine was used to extract information on the marine aquaculture. The main conclusions of this paper are as follows:

(1) The spectral difference between water and the raft aquaculture in high-spatial-resolution remotely sensed images was small, and it was difficult to distinguish them in the spectrum. The B
band extracted by the LBV transformation could enhance the target in water and reduce interference due to water.

(2) The precision of extraction of marine aquaculture using 16×16, 32×32, and 64×64 windows was 90.53%, 92.54%, and 94.37% respectively. The texture eigenvalues extracted by wavelet multi-scale decomposition in this paper contributed to improving the accuracy of interpretation.

(3) The 16×16, 32×32, and 64×64 windows were selected for the wavelet decomposition experiment. The accuracy of the larger windows was higher but banded edges were observed along the boundary. Fine texture could be recognized in smaller windows, but their accuracy was low. Thus, care must be exercised in selecting appropriate windows for extracting information on raft cultivation.

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