Scale Transformation for Remote Sensing Image and Optimal Scale Selection

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Abstract—**The importance of scale issues is described in this paper. It also expounds the situation of the study on scale effect, scale transformation and optimal scale selection. Then, several scale transformation algorithms have been discussed. And the technical characteristics of optimal scale selection method based on pixel and object are researched. In the end, the paper investigates the future directions of the scale issues.**

Index Terms—**scale transformation, optimal scale selection.**

I. INTRODUCTION

The concept of scale has different explanations in different application field. Lam and Quattrochi have defined four kinds of scales related spatial phenomena [1]. Firstly, the mapping scale. Secondly, the geographic scale, also known as the observation scale. It expresses the range of the study area. The wider area we study on, the bigger mapping scale it represents. Thirdly, the operation scale. It means the spatial scope of the geographic phenomena, which decided by the nature of geographical phenomena. The last one is the measurement scale, the same concept as resolution. It is defined as the smallest unit of the spatial dataset. The smaller unit means the higher resolution, but the smaller scale. The paper focuses on the measurement scale.

Image classification is a common method of information extraction. The accuracy of image classification depends on the measurement scale. Foreign scholars began to study the impact of image classification accuracy in the 1980s. Markham and Townshend (1981) proposed that the image classification accuracy is affected by the number of mixed pixels and the spectral variation of categories[2]. When the image spatial resolution improves, the mixed pixels among different categories will be reduced, and the classification accuracy will be improved. However, with the higher spatial resolution, the spectral variation within the same category increases, yet the classification accuracy decreases. In summary, the scale issue is very important. Latty and Hoffer(1981) classified TM images of four different resolutions, with the maximum likelihood method. The result showed that the classification accuracy decreased, with the higher resolution[3]. Chinese scholars also studied the scale effect. In 2006, Huang Huiping used the pixel-based method and the object-oriented method to classify the same image, and tried to study the relationship between object scale and the image resolution. Finally, the test proved the optimal scale depended on the scale of the ground object [4].

In data processing, scale transformation and scale stacking are needed to improve the accuracy of information extraction for the object feature of different scales in the same area. Marceau（1999）held that the loss of information will be inevitably induced by the transformation of different scale images，so there are three noticeable problems. How to determine the optimal scale which is able to express the geographical phenomena correctly, the optimal process and the scale transformation algorithm, and which kind of information loss will be induced by scale transformation [5]. Besides the theoretical research, there are many examples of practical application. Goward etc.(2003) transformed IKONOS image (total chromatic resolution is 1 meter and multispectral resolution is 4 meters) into image with 30 meters resolution(the same as resolution of Landsat ETM+). Then compared the vegetation indexs calculated by the two images[6]. Research work in this aspect in China starts late. In the project of "Theory and Application of Quantitative Remote Sensing of Major Factors for Spatial-Temporal Heterogeneity on the Land Surface" by Li Xiaowen（2006）, series achievements have been acquired on theories of scale effects and scale transformation, quantitative remote sensing inversion based on prior knowledge, and synchronous in-situ, simulation experiments [7].

At present, most optimal resolution selection methods are based on the principle of statistics. For example, Woodcock and Strahler (1987) put forward a method which said the optimal scale is determined by the local variance of remote sensing image. When the local variance reaches its maximum, this resolution will be the optimal scale [8]. In recent years, the method of variation function has wide application. For example, in 1997, Atkinson selected the optimal resolution by calculating the variation function of images of different resolution. When the value of variation function reaches its maximum, the corresponding spatial resolution is just the optimal one [9]. In addition, some scholars have done more research to the methods mentioned above. For example, modified local variance method [10] based on variable window and variable resolution, and the segment parameter selection project based on regional growth method.

II. SCALE TRANSFORMATION

Scale transformation is defined as the process that the image is transformed to one with other spatial or spectral scale. Scale expansion is to transform the image from the small scale to the big scale. And scale contraction is to transform the image from the big scale to the small scale. Scale contraction is realized by image fusion method. In this paper, the scale expansion method will be introduced emphatically.

A. Scale Transformation Method Based on Statistics

Scale transformation method based on statistics concerns data itself. So the spatial or spectral information of remote sensing image is the only element which should be considered.

Explicit understanding of physical mechanism of remote sensing image is unnecessary. The scale transformation method based on statistics contains pixel-based method and object-oriented method according to different image analysis units.

1) Pixel-based Scale Transformation Method

Pixel-based method is a simple method of scale transformation. This method is to integrate the image into a single and bigger window by making a n×n image window as a unit. And it is comparatively simple and easy to implement. There are common algorithms such as local average, center point, nearest neighbor, bilinear interpolation and cubic convolution.

(1) Local average method is to calculate the mean value of the image pixels in the n×n window of the high-resolution image as the value of the pixel of the corresponding low-resolution image, see Fig.1(b). The algorithm of this method is simple, and the new image could keep the mean value information of the original one. But some detailed information will be lost.

(2) Center point method is to make the value of the central pixel in the n×n window of the high-resolution image as the corresponding low-resolution image pixel value, see Fig.1(c). This method is of low computation and could keep the texture of original image. But the image transformation will become discontinuous with the bigger extension window.

(3) Nearest neighbor method is similar to center point method, while the effective pixel is not the central one but the nearest one. So it calculates simply too. And the quality of the transformed image will be lost in some degree, and the result will become discontinuous, because the impact of other neighboring pixel is not considered.

(4) Bilinear interpolation method is to make use of the values of the four neighboring pixels. The first value is calculated from the two pixels in horizontal direction with first order linear interpolation method, and then, the second value is calculated from the two pixels in vertical direction with the same method. The mean value of the first and second value calculated is just the value of the pixel of the corresponding low-resolution pixel value, see Fig.1 (e). The computation of this method is heavy, but the shortcoming of discontinuous phenomenon could be overcome. Meantime，the edge information will be lost in some degree.

(5) Cubic convolution method is a relatively complicated transformation method, and its principle is similar to bilinear interpolation method. 16 pixels of high resolution image in the 4×4 window are averaged according to weighted average method, and then the value of the corresponding pixel of the low-resolution image is obtained, see Fig.1(f). The computation of this method is complicated. Both the neighboring pixel value and the change rate of pixel value are considered. So the texture and edge information could be kept well and the transformation accuracy is better than that of previous methods.

From the figures below, the image of scale transformation could keep the spatial resolution and the spectral character of original image. At the same time, in the process of classification, part of the noise impact could be eliminated and the spectral variation inner category could be reduced. So the classification accuracy and information extraction improve.

(a) (b) (c)

(d) (e) (f)
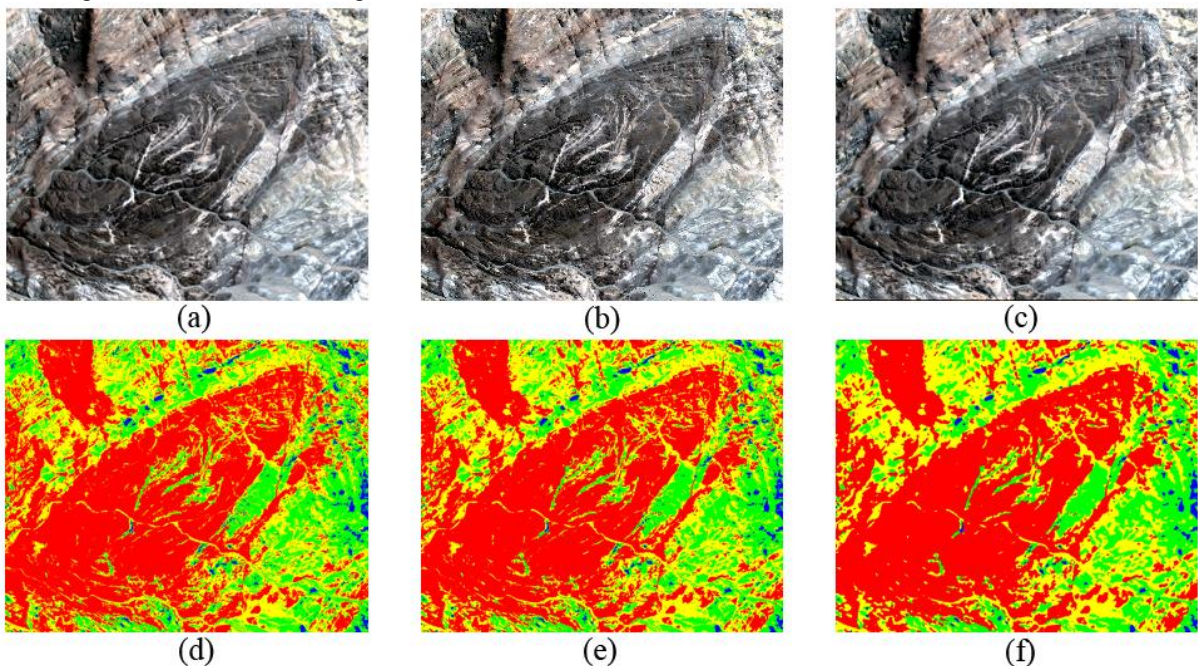
Note: read area represents the granite ; blue area represents the marble; green area represents the alaskite; yellow area represents the metamorphic rock.

a—original image ； b—image of scale transformation by the nearest neighbor method； c—image of scale transformation by the cubic convolution method；d—classification result of original image ； e—classification result of image(b) ； f—classification result of image(c).

Figure1. Contrast of classification result of different scale transformation algorithms

2) Object-oriented Scale Transformation Method

Object-oriented scale transformation method is the extraction and segmentation of the texture character of images. Texture segmentation requires to compress the high-resolution image to a low-resolution image, and keeps the effective information of high-resolution image. Finally, the image will be segmented into multiple polygons with two pieces of principal. One is minimizing the quantity loss of image, the other is keeping the most information of the original image [11].

Object-oriented scale transformation method is a kind of multi-scale segmentation technology. Polygons with different areas (scales) are formed from below by region merging method [12]. Small objects could be merged into a big one after several steps, and the size of each object should be adjusted only when the object heterogeneity is less than the given threshold. Evidently, the bigger segmentation scale means more pixels will be merged and the objects of bigger area will be obtained. The large scale objects are transformed from the merger of the small scale objects, so the hierarchical structure could be formed by the neighboring scale objects. It makes the possibility for information transmission between different structure levels.

After segments the image by multi-scale segmentation method, the basic unit of the image is not a single pixel but a polygon object composed of homogeneous pixels. The spectral information of the pixels included in every polygon and the information of shape, texture and position of the polygon as well as the topological relation among the polygons should be calculated firstly. Then all kinds of information provided by objects could be chosen to combine. Detailed classification rules of different level and different scale are established to extract information according to the different ground object types. There is corresponding relationship between each layer, so classification rules could also be transferred between layers.

B. Scale Transformation Based on the Mechanism

Scale transformation based on the mechanism will build the transformation model with multiple variables, and then predict the low-resolution image from the high-resolution image. This method is more coincident with the imaging process mechanism. So the physical meaning of this method is more explicit. And the classification accuracy is higher than the transformation method based on statistics. However, because of the different object type, scene and imaging process, the model is very difficult to build. So errors of the transformation result are inevitable.

The point spread function is a signal processing method. It detects the energy distribution of a pointolite catches by the sensor. This method should filter the image by a weight matrix, which is simulated at the beginning. Then resample the image to reduce the spatial resolution. The weight of every pixel depends on the distance from the central pixel. In other words, the smaller weight comes from the larger distance.

In summary, the scale transformation method based on statistics concerns data itself. It transforms the image scale according to the spatial or spectral data. So the algorithm is simple. The scale transformation method based on mechanism concerns the physical mechanism of the remote sensing. It transforms the image scale according to the imaging process parameters of the sensor and the geological process parameters. So it is more difficult for the second method.

III. OPTIMAL SCALE SELECTION

Because of the scale issues, we should select the most appropriate scale to describe the spatial distribution features of ground objects as far as possible, according to different purposes. The optimal scale selection method will be discussed in this paper. One is the pixel-based method. The other is the object-oriented method.

A. Pixel-based Optimal Scale Selection

There are two requirements of the pixel-based optimal scale selection method. One is to describe the spatial distribution characteristics as far as possible. The other is to choose the minimum resolution based on the first requirement. If there are many types of ground objects in the same image or the same region, we should select the optimal scale by identifying the smallest feature type. The local variance is the most common and simple method.

The local variance method was introduced by Woodcock and Strahler to select the optimal scale [8]. The local variance method calculates the mean value of the local variance of every window, and then finds out the variation between spatial resolution and average local variance, see Fig.2. When the window size is （2m+1）×（2n+1）,the local variance is based on the Equation 1.

$$S^2 = \frac{\sum_{i-m}^{i+m}\sum_{j-n}^{j+n}[X_{ij}-\mu_{ij}]^2}{(2m+1)(2n+1)-1} . \qquad (1)$$

Where $X_{i,j}$ is the pixel value of row i and column j, $\mu_{i,j}$ is the mean value of the pixel values within the window which size is （2m+1）×（2n+1）, and whose central pixel in row i and column j, m and n control the size of the window.

B. Object-oriented Optimal Scale Selection

The essence of the object-oriented method is the regional selection. And the principal of the selection is to make the maximum regional heterogeneity and the minimum inner-regional heterogeneity. So, this method needs to calculate the area of different object polygons, and finds out the resolution of the smallest object. Then choose the optimal
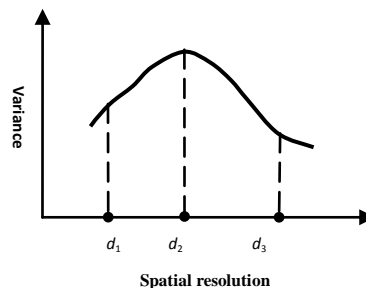

Figure2. Schematic curve of spatial resolution to local variance
（After Woodcock，1987）

scale by the variance.

It is different from the pixel-based optimal scale selection method, the object-oriented method calculates the variance by the unit which is divided into different window scales, and then chooses the optimal scale. It could be implemented by three steps. To segment different size windows based on the object-oriented scale transformation. To calculate the mean value of every window and the whole image afterwards. Moreover，to calculate the variance of different windows, and then to draw a variance-scale curve. There will be many peak values on the curve. Every scale of the peak value presents the optimal scale of each kind of object.

In conclusion, the pixel-based optimal scale selection method is suitable for similar scale ground objects. However, the object-oriented optimal scale selection method is suitable for the image contains different scale ground objects. The object-oriented optimal scale selection method considers both spectral heterogeneity and shape heterogeneity. So the classification accuracy and efficiency of the object-oriented method is higher than the pixel-based method.

IV. CONCLUSIONS

According to the research status at home and abroad, this paper describes some methods of scale transformation and optimal scale selection. It also summarizes advantages and disadvantages as follows.

The scaling method based on statistics is easy to implement. But the classification accuracy is lower. However, the scale transformation method based on mechanism depends on the physical mechanism of the imaging process and the geological process. The second method of higher classification accuracy is much more difficult to implement.

The pixel-based optimal scale selection method is suitable for similar scale ground objects. The principal and process of this method are simple. However, the object-oriented optimal scale selection method is often used for another kind of images which contain different ground objects. It will improve the classification accuracy. But the calculation process is more difficult.

There are many advantages and disadvantages of different methods. So the key point of the information extraction is how to choose the best method and the optimal scale.

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