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Review of Remotely Sensed Imagery Classification Patterns Based on Object-oriented Image Analysis

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Abstract: With the wide use of high-resolution remotely sensed imagery, the object-oriented remotely sensed information classification pattern has been intensively studied. Starting with the definition of object-oriented remotely sensed information classification pattern and a literature review of related research progress, this paper sums up 4 developing phases of object-oriented classification pattern during the past 20 years. Then, we discuss the three aspects of methodology in detail, namely remotely sensed imagery segmentation, feature analysis and feature selection, and classification rule generation, through comparing them with remotely sensed information classification method based on per-pixel. At last, this paper presents several points that need to be paid attention to in the future studies on object-oriented RS information classification pattern: 1) developing robust and highly effective image segmentation algorithm for multi-spectral RS imagery; 2) improving the feature-set including edge, spatial-adjacent and temporal characteristics; 3) discussing the classification rule generation classifier based on the decision tree; 4) presenting evaluation methods for classification result by object-oriented classification pattern.

Keywords: object-oriented image analysis; remote sensing; classification pattern

1 Introduction

With the rapid development of remotely sensed (RS) information collection, transfer and storage in the last two decades, the limitation of RS application is becoming weaker because of availability of multiple RS data sources of increasingly finer spatial, temporal, spectral and radiant dimensions. In the high spatial-resolution RS imagery, characteristics of land-cover are fairly clear such as spatial shape, structure, texture, etc., so the mixture of different land covers in a single pixel is lessening. At the same time, more types and differences of land covers in the high spatial-resolution RS imagery have been shown compared with middle and low spatial-resolution RS imagery (Dou, 2003). However, the traditional RS information classification methods seldom take full use of land-cover characteristics such as shapes, structure information, and spatial distribution in high spatial-resolution RS imagery, which causes large amount of resources waste and becomes a bottleneck for the application of RS technology. In a word, the increasing variety of satellites and sensors and better spatial-resolution will have an influence on a broad spectrum of application but not automatically lead to better results. Therefore, how to exactly extract useful information from high spatial-resolution RS imagery in a quick but efficient way becomes a hotspot of current research.

2 Definition of Object-oriented Classification Pattern

RS information classification pattern is defined as one general technology of extracting land-cover classification information from RS imagery. Citing a famous formula from Niklaus Wirth (1975): "Program= Algorithm + Data Structure", we describe RS information classification pattern as follows:

RS Information Extracting Pattern = Processing Unit + Feature Set+Classifier

In the above formula, a pixel or an object (a combination of similar pixels) is the basic processing unit in RS image processing. Feature set is a set of features, which could be extracted from RS imagery or relative GIS data source. Classifier can be an individual classifier, such as statistical classifier (K-means, Iterative Self-organizing Data Analysis Techniques Algorithm, Maximum Likelihood Classification, Minimum Distance, Parallelepiped, Spectrum Angle, etc.), artificial neural network classifier (Back Propagation, Kohonen, etc.), machine learning classifier (Decision Tree, Classification and Regression Tree, etc), fuzzy classifier (Wang and Li, 2004), or the combination of different classifiers according to special mechanism (such as voting mechanism) (Bo and Wang, 2003). According to the difference in processing unit, we categorize the RS information classification patterns into two types: RS information classification pattern based on

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per-pixel (shortened per-pixel classification pattern in the following text) and object-oriented RS information classification pattern (Fig. 1).

Per-pixel classification pattern analyses per-pixel spectrum characteristics, and categorizes each pixel into a certain class by statistical methods (such as discriminant function, clustering) (Zhao, 2003), which was brought forth in the early 1970s and is a rather mature technique.

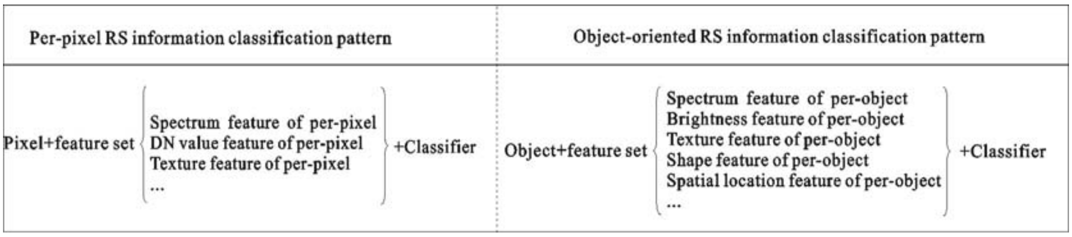

Fig. 1 Two types of remotely sensed information classification pattern

Object-oriented classification pattern deals with image objects①, which share the similar attributes, such as Digital Number (DN) value, spectral characteristics, texture, size, shape, compactness, context information with adjacent image objects, etc. (Blaschke and Hay, 2001; Blaschke and Strobl, 2001). The image objects can be extracted through RS image segmentation technique (to put similar characteristic & spatial conjoint pixels into a same image object). Object-oriented classification pattern uses the image objects as the basic processing units, calculates per-object's characters, and extracts land-cover information from RS imagery.

3 Development Phases of Object-oriented Classification Pattern

Object-oriented classification pattern booms with the progress of image segmentation technique and the widespread of high spatial-resolution RS imagery, which can be dated back to the complex aerial photographs interpretation system built by Nagao and Matsuyama (1980). In that system, image segmentation technique guided by knowledge and feature-analysis was adopted to improve extraction accuracy. As a special technical term, object-oriented RS information extraction pattern came into being in 2000 (symbolized by the release of e-Cognition software, guidance under the object-oriented image analysis theory).

In National Library of China and Institute of Scientific & Technical Information of China, through Elsevier Science Direct Onsite, ProQuest Academic Research Library, EBSCO Online Citation, and Google Search Engine, etc., 105 papers related were found in English version up to May, 2004 (including 5 papers before 1999, 5 in 2000, 23 in 2001, 27 in 2002, 45 in 2003, search key words are object-oriented, remote sensing, pixel based, per-pixel, per-parcel, etc.). Among the search results, domestic research were almost blank, only 3 scientific papers and 1 dissertation (published in 2003 and 2004) were found using search engine such as Wanfang Dissertation Database, Wanfang Conference Database, Chinese Journal Full-text Database (CJFD), China Knowledge Resources Integral Database (CNKI). As for the number of scientific papers published every year, object-oriented classification pattern become a hotspot research gradually. In contrast, domestic research on object-oriented classification pattern should be strengthened. Analyzing the related literatures at home and abroad synthetically, object-oriented classification patterns can be summarized into four phases as follows:

(1) Thoughts on per-pixel classification pattern. Toll (1984) and Martin et al. (1988) compared RS information extraction results using Multi-spectral Scanner (MSS), Thematic Mapper (TM), SPOT imagery of the same study area, and found the pattern simply using statistical analysis technique based on per-pixel can not get higher classification accuracy effectively along with the improvement of image's spatial-resolution. Lobo et al. (1996) used per-field or per-parcel classification method and enhanced the classification accuracy, adopting image analysis technique. Additionally, classification result can be more easily explained than per-pixel classification pattern, which often cause "pepper phenomenon" after smooth processing. Similar researches also indicate that per-field or per-parcel classification method has positive effect on middle or high resolution RS imagery. This classification technique is especially applicable for agricultural land or other pre-defined, spatially discrete land cover types. Distinct boundaries between adjacent agricultural fields help to improve the classification due to the fact that boundaries in an agricultural landscape are relatively stable while the cropping pattern (also within the lots) changes frequently (Aplin et al., 1999; Chen et al., 2003). Anna et al. (2001) detected edge information from TM multi-spectral data by region growth method, and extracted land cover information considering length and direction of boundary between different land-cover,

① In Webster dictionary, "object" is defined as something material that may be perceived by the senses. In software engineering, "object" is foundational component of the system, and is an entity with special property (data) & manner (procedure), and "object-oriented" is a kind of program design technique to ensure software quality and boost coding efficiency.

and they drew a conclusion that classification result based on similar characteristic pixels is better than per—pixed classification method. With the appearance, prevalence of high resolution RS imagery, researchers gave much consideration to the disadvantage in per-pixel classification process. Blaschke and Strobl (2001) put forward "Why are remote sensing and digital image processing still so much focused on the statistical analysis of single pixels rather than on the spatial patterns they built up?" In his paper, several prominent but always neglected problems are summarized as follows: 1) Basic processing unit in traditional RS information classification pattern is pixel, which just stands for regular certain of the earth's surface without consideration of context, so it is rather difficult to integrate with GIS spatial analysis (usually in vector format) in raster format. 2) Although spatial location information is noticeable in RS imagery, but it is redundant and is often neglected in per-pixel classification method. Pixel in any place will be partitioned to certain class simply by spectrum information. "Image object" corresponding to entities in real world bridges the methodology domains of GIS and RS/IP (Image Processing System, IPS), and provides an opportunity to integrate GIS analysis with image processing. Chen et al. (2003, 2004) pointed out that image analysis based on per-pixel is in the bottom of image engineering, and is subjected to the field of image processing, but not real image analysis to some extent. As a result, to upgrade high resolution RS imagery information classification process from RS image process to RS image analysis and up to image understanding is impending requirement of RS.

(2) Presentation of concept of "image object". Hay et al. (1997) first described: Image object is self-existent and resoluble entity in digital image, pixels in entity have similar characteristics. And in 2001, they further indicated that those image objects satisfy Tobler's first law of Geography①. Blaschke (2002) pointed: on most occasions, semantic information of certain image should be expressed by the means of "meaningful objects" and correlation among them, not by single pixel. Only based on dividing an image into different homogeneous objects, can image analysis come to true (Blaschke, 2002). With the appearance of concept of "image object", thousands of segmentation algorithms have been developed in the past decades. Although a lot of developments in segmentation of grey tone images in related fields, like robotic vision have been made, there has been little progress in segmentation of color or multi-band imagery. Under the background, some aero-image understanding prototype system came into being, such as Zhang et al. (2000) developed a fast semiautomatic algorithm to extract house information from aero-image, which adopted geometry restriction and image segmentation technique. Yang and Zhao (2002) aimed at the characteristics of building's brightness greater than background, and put forward building detection algorithm based on region segmentation.

(3) Appearance of object-oriented classification pattern. A new algorithm, called "Fractal Net Evolution Approach" (FNEA, by Baatz and Schipe, 1999) could revolutionize image processing of remotely sensed data (De Kok et al., 1999; Niemeyer et al., 1999). In order to reduce the heterogeneity of the final segmentation result, FNEA merged a pixel with adjacent pixels following a local mutual best fitting rule at a given scale. After all the pixels amalgamated to different objects, the next combination is performed based on the objects generated in previous round till any iteration cannot to be continued in the scale given by the user. Delphi2 Creative Technologies Corp. in Munich, Germany applied the FNEA algorithm to e-Cognition (the latest Version is 4.0) and put it to the market in 2000, which is the unique software under the guidance of object-oriented image analysis principle till now.

(4) Application of object-oriented classification pattern. The application of the object-oriented classification pattern to different RS imagery sources (including TM, ETM+, SPOT, SAR, KOMPSAT-1, IKONOS, Quick-Bird，etc.) and classification result comparison of the two patterns have attracted much attention. Such studies include: Bauer and Steinnocher (2001) in Vienna urban district, Austria using IKONOS multi-spectrum data; Martin and Joseph (2002) in Santa Barbara using 4m IKONOS data; Rego and Koch (2003) in Brazil Pedra Branca National Park; Kressler et al. (2003) in Vienna forest dependency using KOMPSAT-1 & SPOT-5 panchromatic RS data; Du et al.(2004) in Nanjing using IKONOS multi-spectrum RS imagery; Huang et al. (2004) and Huang and Wu (2004) in Daqing using chromatic aero-image data. Most researches indicate that object-oriented classification pattern for high resolution RS imagery can acquire higher classification accuracy than per-pixel classification pattern.

With the spread of object-oriented classification pattern, domestic researchers have paid attention to its methodology since 2004. Liu et al. extracted high quality prime farmland (HQPF) using an algorithm of multi-spectral remotely sensed image segmentation based on edge information (Liu, 2004; Liu et al., 2006). Ming et al. (2005) designed a multi-scale information extraction framework based on characteristics of object to improve RS imagery process automation and intelligentization level.

4 Basic Steps of Object-oriented Classification Pattern

4.1 RS imagery segmentation

RS image segmentation is the basic and first step of object-oriented classification pattern (Fig. 2). The purpose of the RS image segmentation is to generate elementary

① Tobler's first law of Geography: objects are related to all other objects, but proximal objects are more likely to be related to each other.

image objects, which are primary processing units in image classification process. Further image analyses including feature analysis, feature selection and discriminant rule generation are based on image segmentation. In per-pixel classification pattern, the basic processing unit is pixel, which exists naturally without any processing. While in object-oriented classification pattern, image objects generated through RS image segmentation step are basic processing units, and correspond with the land-cover entities in the real world. Only based on above preparation, has further work the opportunity to succeed. So the result of RS image segmentation will directly influence further analysis and processing.

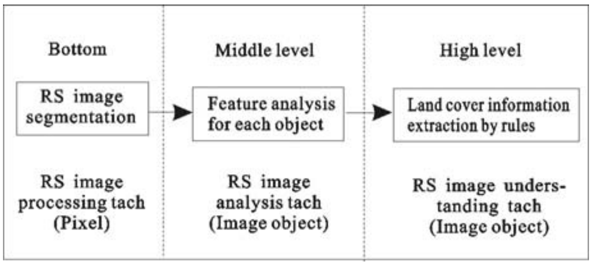

Fig. 2 Image segmentation in object-oriented RS analysis

Most of RS image segmentation algorithms origin from “image segmentation” in robotic vision field, and can be sorted into four classes: 1) image segmentation algorithm from top to bottom based on threshold slice (Han and Wang , 2002), such as self-adaptation threshold slice based on histogram, threshold slice based on maximum classes square error (OSTU method), method for gray-level threshold selection based on maximum entropy, etc.; 2) image segmentation algorithm based on region (Li and Xia, 2002; Li and Zhang, 2003), such as region growth method, split-combination algorithm, water-shed algorithm, etc.; 3) image segmentation algorithm from bottom to top based on iterative clustering method (Li and Huang, 1992; Zhang and Li, 2001) , such as K-means feature clustering method, clustering method based on MARKOV random-field, clustering method based on neural network; 4) image segmentation algorithm based on a given model (Liu and Chen, 1999; Zhang et al., 2003) , such as active contour method (ACM), image segmentation algorithm based on energy function, image segmentation algorithm based on minimum description length (MDL), etc. But most of the image segmentation algorithms mentioned above aim at grey-scale or chromatic image (three bands). FNEA adopted by e-Cognition can deal with multi-bands RS imagery, and is almost the best algorithm among them.

4.2 Feature analysis

In the process of RS image interpretation, features of land-cover appearing in the imagery play an important role. Interpreters synthetically use hue, color, shape, size, shadow, texture, situation, pattern, etc. to extract land cover information. These characteristics should be calculated and expressed in digital format, in order to assist computer differentiate each other. Zhou et al. (1999) generalized available features into three types: spectral, spatial and temporal features. Yan and Wang (2002) pointed these features are pyramidical (Fig. 3). In the top pyramid is hue and color feature of the RS imagery, which reflect characteristic of land cover; in the middle of the pyramid is size, shape, texture, which can be regarded as spatial layout of top features; the bottom of pyramid reflects location, spatial relationship, dynamic change process of land cover.

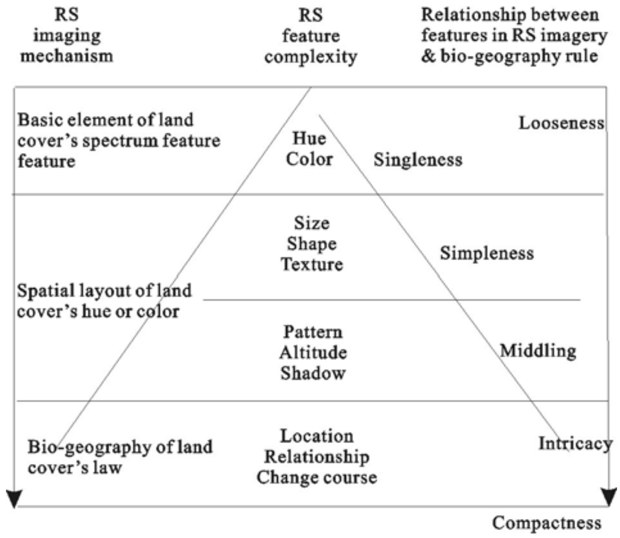

Fig. 3 Features in RS imagery

In traditional per-pixel classification pattern, feature analysis is calculated based on pixels. Methods of feature analysis include RS imagery spatial, radiometric, spectral enhancement，etc. In object-oriented classification pattern, feature analysis is calculated based on per-object. Limited features of the pyramid showed in Fig. 3 can be used to per-pixel classification pattern, which is almost in the upper of the pyramid. There are more features that can be extracted in object-oriented classification pattern. For example, characteristics of the image objects include spectrum, shape, spatial layout, texture, architecture, etc. in e-Cognition software (Definients Image GmbH, 1999). In addition, some limitations exist in the feature analysis: 1) Pixel in the RS imagery just stands for regular region of the earth's surface, which is strongly influenced by multi-factors in the process of imaging. Single and random noise points have great impacts on the classification result. 2) In pixel level, it is difficult to calculate some regional features (such as shape characteristic of airport) before classification, and usually need special process (such as raster to vector procedure) (Li, 1995; Du et al., 2001; Qin et al., 2001). 3) Additionally, it is difficult to directly apply some features of the image object to the RS imagery information extraction process based on per-pixel. In object-oriented classification pattern, image object is the aggregation of similar pixels by image segmentation method, so the formation of image objects is a weighed mean process and can reduce the influence of random noise point which decreases the above limitations. On the other hand, characteristics computed based on per-object can be directly applied to the process of RS imagery information classification/extraction.

4.3 Classification information extraction

In comparison with RS image segmentation and feature analysis steps, there is little difference in classification information extraction step between per-pixel pattern and object-oriented classification pattern. Most classifiers such as statistical classifier, machine learning classifier, and fuzzy classifier can be applied to the two classification patterns. For example, the e-Cognition4.0 adopts fuzzy classifier and takes building fuzzy rule library and anti-fuzzy step to extract land-cover information, based on the image object generated by FENA method. The difference only lies in the processing unit: the former is per-pixel and the discriminant criterion of classification is based on per-pixel, while the latter is per-object and the discriminant criterion of classification is based on per-object. Because image object is a set of homogeneous or similar pixels, the latter costs shorter time in classification information extraction step.

5 Prospect of Object-oriented Classification Pattern

According to the above analysis on concept, development phases, and basic steps, the object-oriented classification pattern can make full use of spatial shape, structure, texture characteristic, etc., in high resolution RS imagery, which stands for an important trend of RS thematic information extraction. But as far as it goes, several points that should be focused on and paid attention to during the development of object-oriented RS information extraction pattern are as follows:

(1) In most literature, few methods were discussed except for a few papers on FENA. In contrast to most image segmentation algorithm, FENA is a reliable image segmentation algorithm, which can deal with multi-band RS data, and be able to integrate DEM data. But it is intensely subjective in scale selection and confirmation of weight of color/shape, which entirely depend on processors' estimation and can cause potential limitation of image segmentation result. How to effectively and rationally segment RS image into meaningful image objects corresponding to geographical entities should be discussed in methodology in-depth.

(2) Although a feature-set which can be analyzed from RS imagery has been built in e-Cognition software, it needs to be improved in edge characteristic of image object, temporal feature, spatial-adjacent characteristic, etc. In addition, in the process of RS image information extraction or classification based on feature space, it is not true that the more features result in the better accuracy. Some characteristics are critical, playing a significant role in classification/extraction process, but others are secondary and assistant, playing a minor role; besides, there exists noises that play an insignificant or even negative role. So in the condition of object-oriented image analysis, the method how to select significant character/features involved in the process of classification is seldom described in the literature.

(3) The classifier used in e-Cognition software is fuzzy classifier and serves as a "black-box" in the classification process, while the classification rules are so difficult to be understood that users do not know how the mechanism differentiates an object into a certain class. And most of all, the knowledge gained in the classification process (always the rules) usually can not be transferred to another classification process, even in the same research area. This is the reason why we can get the classification result but do not know the inside story. Additionally, selection for training area should be repeated again and again when having a RS image classification task, this greatly restricts automation of RS information extraction. Decision tree classifier (DTC) can deduce impersonal and user-understanding classification rules from training dataset, and the rules have finer transferability and are conveniently expressed in chart form (tree structure). In RS imagery application, this kind of classifier has been used occasionally. Image objects generated by image segmentation correspond with the entities in the real-world, and have more advantage in rule expression. On the understanding that combining DTC and object-oriented method to generate reusable, transferable classification rules (knowledge), it will accelerate the automation process of RS information extraction.

(4) Evaluation method for classification result by object-oriented classification pattern should be strengthened. Accuracy assessment is an indispensable step in RS imagery information classification process. Researchers can ensure the validity of classification method and improve the classification accuracy based on the enhanced methods. In traditional per-pixel classification pattern, evaluation method goes through a mature way from qualitative analysis based on human interpretation based on confusion matrix. But the outcomes of RS information extraction relate to not only land cover type-coherence, but also shape-coherence and area-coherence. How to evaluate the shape-coherence, type-coherence and area-coherence in the condition of object-oriented image analysis had rose to researcher eyeshot.

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