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An automated satellite image classification design using object-oriented segmentation algorithms: A move towards standardization

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Abstract

Numerous segmentation algorithms have been developed, many of them highly specific and only applicable to a reduced class of problems and image data. Without an additional source of knowledge, automatic image segmentation based on low level image features seemed unlikely to succeed in extracting semantic objects in generic images. A new region-merging segmentation technique has recently been developed which incorporates the spectral and textural properties of the objects to be detected and also their different size and behaviour at different stages of scale, respectively. Linking this technique with the FAO Land Cover Land Use classification system resulted in the development of an automated, standardized classification methodology. Testing on Landsat and Aster images resulted in mutually exclusive classes with clear and unambiguous class definitions. The error matrix based on field samples showed overall accuracy values of 92% for Aster image and 89% for Landsat. The KIA values were 88% for Aster images and 84% for the Landsat image.

Keywords: Object-orientation; Land use and land cover; Automation; Standardization

1. Introduction

There is a demand for tangible landscape objects at several scales which are internally relatively homogeneous on which one can apply spatial statistics and, to assess changes. Various approaches in computer vision, pattern recognition, image analysis, landscape ecology and environmental monitoring are in search of such objects. The classification quality is directly dependent on the quality of extracted objects. Object-oriented image classification is based on the fact that important semantic information necessary to interpret an image is not represented in single pixels, but in meaningful image objects and their mutual relations. A strong and experienced evaluator of segmentation techniques is the human eye/brain combination. By applying segmentation procedures to the automation of image analysis, the activity of visual digitizing is replaced.

Recent applications of image segmentation and image understanding techniques require increased robustness, better reliability and high automation of the algorithms. While traditional methods of region based (region growing, texture based segmentation) (Aguado, Montiel, & Nixon, 1998; Bezdek, 1981; Li, Wang, & Wiederhold, 2000; Liu & Yang, 1994; Ronfard, 1994) and edge based (snakes, dynamic programming) (Canny, 1986; Pal & Pal, 1994) image segmentation algorithms continue to be explored with attempts to improve their performance by adding expert knowledge to their detection criteria, new model driven techniques have been developed—active shape models, active appearance models (Cootes, Edwards, & Taylor, 1998; Cootes, Taylor, Cooper, & Graham, 1995). Performance of traditional approaches to edge-based image segmentation is being improved by utilizing advanced segmentation criteria that reflect higher level of knowledge about the segmented object (Gorte, 1998).

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In most applications, however, this expert knowledge is not derived automatically, but introduced by an observer and then translated to mathematical form. This approach requires expert knowledge of the given problem and is usually time consuming when new application has to be designed. Use of information about object shape and form is usually very limited or is not considered at all in the pixel-based approaches.

Baatz and Schäpe (1999a, 1999b, 2000) developed a new region-merging segmentation technique which incorporates the spectral and textural properties of the objects to be detected and also their different size and different behaviour on different stages of scale, respectively. The concept of scale is important in image analysis as most environmental dimensions possess one or more domains of scale (Wiens, 1989) at which the individual spatial or temporal patches can be treated as functionally homogeneous.

The concept of heterogeneity (and homogeneity) is perhaps the key characteristic of every landscape and underlies the scale factor in images. It may be defined as the uneven, non-random distribution of ecological units. There are three types of heterogeneity: temporal, functional and spatial. In the image multi-scale segmentation, the quantitative criterion for the evaluation of the segmentation results is that the average heterogeneity of pixels is minimized. Each pixel is weighted with the heterogeneity of the image object to which it belongs. The qualitative criteria are the fact that any segmentation results have to satisfy the human eye and the information, which can be extracted from image objects for further successful processing.

With satellite remote sensing techniques now becoming the single most effective method for land cover/land use data acquisition, it is imperative that standardized, object-oriented approaches to image analysis be developed. Anderson, Hardy, Roach, and Witmer (1976) developed a hierarchical land use and land cover classification system for use with remote sensor data. The Anderson derived land use and land cover classifications have been adopted in most contemporary systems including the FAO Land Cover Classification System (FAO, 2000). This system is created specifically for mapping purposes; it uses a set of independent diagnostic criteria, the classifiers, rather than being nomenclature based. This allows each class to be clearly and systematically defined, thus producing internal consistency. The LCCS specific design allows incorporation into GIS and databases and it was combined with the multi-resolution image segmentation procedure.

The primary objective of this research was to develop a standardized, object-oriented classification method, with automation capabilities. This article reports on the development of a method based on linking object-oriented image analysis techniques in eCognition and the FAO land cover classification system. ASTER datasets were used and the automation capabilities of this technique were tested on other ASTER images taken at the same period. To assess application of the method on another satellite images, classification of a Landsat TM image was also undertaken.

2. Background

2.1. A ‘new’ paradigm—multi-scale image segmentation

Multi-resolution segmentation is a bottom up region-merging technique starting with one-pixel objects. In numerous subsequent steps, smaller image objects are merged into bigger ones. Throughout this pairwise clustering process, the underlying optimization procedure minimizes the weighted heterogeneity nh of resulting image objects, where n is the size of a segment and h an arbitrary definition of heterogeneity. In each step, that pair of adjacent image objects is merged which stands for the smallest growth of the defined heterogeneity. If the smallest growth exceeds the threshold defined by the scale parameter, the process stops. Doing so, multi-resolution segmentation is a local optimization procedure. Baatz and Schäpe (2000) developed decision heuristics to determine the image objects that will merge at each step and definition of homogeneity of image objects to compute the degree of fitting for a pair of objects.

Given a feature space, two objects are considered similar when they are near to each other in this feature space. For a d-dimensional feature space the heterogeneity h is described by

$$h = \sqrt{\sum_d (f_{1d} - f_{2d})^2} \tag{1}$$

Examples for appropriate object features are for instance mean spectral values or texture features, such as the variance of spectral values. The distances can be furthermore standardized by the standard deviation over all segments of the feature in each dimension

$$h = \sqrt{\sum_d \left(\frac{f_{1d} - f_{2d}}{\sigma_{fd}}\right)^2} \tag{2}$$

The degree of fitting of two adjacent image objects can be defined by describing the change of heterogeneity h_{diff} in a virtual merge. Given an appropriate definition of heterogeneity for a single image object the increase of heterogeneity in a merge should be minimized. There are different possibilities to describe the change of heterogeneity h_{diff} before and after a virtual merge

$$h_{\text{diff}} = h_m - \frac{h_1 + h_2}{2} \tag{3}$$

This definition corresponds to the requirement of a quantitative criterion, which aims to minimize the average heterogeneity of image objects when evaluating a segmentation. It can be improved by taking into account the object's size n

$$h_{\text{diff}} = h_m - \frac{h_1 n_1 + h_2 n_2}{n_1 + n_2} \tag{4}$$

An alternative is to weight image object heterogeneity with the object size, thus fulfilling the quantitative criterion which states that average heterogeneity of image objects weighted by their size in pixel should be minimized