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Object-oriented change detection for the city of Harare, Zimbabwe

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Abstract

Object building and the extraction of homogeneous landscape units on which spatial statistics can be applied is useful in assessing land use and land cover change. Object-oriented processing techniques are becoming more popular compared to traditional pixel-based image analysis. A hierarchical image segmentation approach was adopted to extract the objects from multi-temporal Landsat images over Zimbabwe. The spatial arrangement of t_0 and t_1 objects was independent as the segmentation process was independently applied, although object change of t_1 was based on t_0 boundaries. We applied a Standardized, Object Oriented, Automatic Classification (SOOAC) method based on fuzzy logic. The error matrix for the TM image had an overall accuracy of 95.6% and a KIA value of 94.7%, the ETM showed slightly lower overall accuracy. Various LULC changes were identified over the 13 year period per object and also per class, mainly vegetation decrease. Object-oriented change information is necessary in decision support systems and uncertainty management strategies. This approach addresses some of the major issues in object-based GIS change analysis as it is based on stable object geometry.

Keywords: Remote sensing; Satellite; Land use; Land cover; Object-oriented; Change detection; Classification; Sustainable development

1. Introduction

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times (Singh, 1989). Change detection is an important process in monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution of the population of interest. Many researchers and planners have recognized the importance of land use data in urban planning and management (Douglas, 1994; Kaiser, Godschalk, & Chapin, 1995; Van Helden, 1994). The use of remote sensing in updating land use data has had little success in urban areas at the parcel level (Martin, Howarth, Gong, & Holder, 1989).

Change detection has had various applications within land use and land cover analysis. The most commonly used approach is to classify each image pixel as an independent observation regardless of its spatial context. Unfortunately, this is fraught with the limitations imposed by pixel-based image analysis. The general approach to symbolic identification is to compare two classifications pixel by pixel, although it generally results in low change detection accuracy (Singh, 1989). Though several of these applications are dealing with land use and land cover analysis, most of them do not involve independent dissections of image data under consideration. These approaches typically force new dissections to obey existing boundaries either derived from imagery or existing geo-spatial datasets (Blaschke, 2004). The shift towards object orientation is driven by the limitations of the pixel in addressing the issues of location, scale, neighbourhood and distance (Strobl & Blaschke, 2001).

During the last three decades, a large number of change detection methods have evolved that differ widely in refinement, robustness and complexity (Lambin, 1996; McLeod and Congalton, 1998; Muchoney and Haack, 1994; Sailor et al., 1997; Singh, 1986, 1989; Tateishi and Kajiwara, 1991; Wismann, 1994). Hay and Niemann (1994) summarize 10 different change detection algorithms that were found to be documented in the literature by 1994 most of them based on the pixel. Recent overviews of change

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Table 1
Advantages/disadvantages of the segmentation based object-oriented classification versus pixel-based multi-spectral classification

Method	Evaluation
Segmentation process as a technical process (on different scales)	Challenging, no standards
Building relations to neighbour sub-, super-objects	Easy using GIS functionality, intrinsic process in object-oriented environment
Data fusion (different sensor, resolution, raster, vector data)	High potential
Re-usable semantic models (classes)	High potential
Feature analysis (spectral, shape,neighbourhood relation features)	One of the main strengths
Usability, initial learning curve	Similar
Defining scale parameter for segmentation	Difficult, most problematic issue
Automation, repeatability, transferability	High potential, first empirical tests, e.g. Flanders, Hall-Beyer and Pereverzoff, (2003)
Performance	Depends on the image size
Accuracy assessment	Unsolved so far in the *o–o* environment

Moeller and Blaschke (2005).

detection techniques can be found in Hall and Hay (2003), Aplin (2004) and Blaschke, 2004b. Singh (1989) and Coppin and Bauer (1996) both provide excellent and comprehensive summaries of methods and techniques of digital change detection. Deer (1998) categorized the methods based on the notion of pixel, feature and object level. The pixel level normally requires further analysis as the computations involve numerical values of each image band (e.g. image differencing; image rationing). The *feature level* involves transforming the spectral or spatial properties of the image (e.g. principal component analysis, texture analysis or vegetation analysis). The *object level* requires the most advanced processing.

The term object refers to the representation of real world phenomenon in an information system (Kim, 1990). The term 'image object' (Hay & Niemann, 1994) refers to individually resolvable entities located within a digital image that are perceptually generated from high-resolution pixel groups. An object may exist as a physical or conceptual entity and in proving the existence or non-existence of an object, identity is a key factor (Hornsby & Egenhofer, 2000). Object identity is a trait that distinguishes an object from all others (Khoshafian & Copeland, 1986). It provides a way to represent the individuality or uniqueness of an object, independent of its attributes and values (Hornsby & Egenhofer, 2000). Change generally refers to the fact that an object or phenomena is altered or transformed into something different through the result of some action or process (Hornsby & Egenhofer, 2000). In this paper, we confine our discussion to change as it applies to identifiable, discrete objects and focus, in particular, on describing changes with respect to the identity states of objects – i.e. tracking the existence of an object over time.

1.1. Pixel versus object-oriented image analysis

The field of image classification is experiencing a paradigm shift from pixel-based to object-oriented image analysis techniques in landscape analysis. Initial work was in the fields of GIS, neural networks (refs), etc. Image segmentation is not a recent development (Haralick & Shapiro, 1985, Chapater 9: Texture; Ketting & Landgrebe, 1976), but only a few number of image analysis software makes use of this approach and lead to qualitatively convincing results while being robust as well as operational. The high degrees of freedom must be reduced to a few which are satisfying the given requirements. Additionally, segmentation needs to address a certain scale, most segmentation approaches do not allow the specification of several scale levels of image segments and therefore disregards the level of detail or generalisation as well. Table 1 compares the pixel-based approach versus the object-oriented approach.

The move towards object-oriented image analysis is often associated with the commercial success of Definiens Professional[1] (Benz, Hofmann, Willhauck, Lingefelder, & Heynen, 2004). This is 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. It allows the segmentation of an image into a network of homogeneous image regions at any chosen resolution. These image object primitives therefore represent image information in an abstracted form and serve as building blocks and information carriers for subsequent classifications (Baatz & Schape, 2000).

The first step in the classification process is the definition of desired classes for each segmentation level. Once the classes have been named, their specific characteristics have to be defined. Those characteristics are not only the spectral reflectance values used for the statistical evaluation but also parameters like: size, shape, and perimeter, texture, neighbouring relations as well as relations to sub or super objects. A huge toolbox can be utilized for the explicit definition of classes in the object-oriented classification software. Borders between neighbouring classes with only slight differences can be described with a soft transition from one class to another class using fuzzy rules.

A number of change detection studies have been undertaken since 2000 incorporating a multi-scale object-oriented analysis. Willhauck, Schneider, De Kok, and

[1] Formerly known as eCognition developed by Definiens Imaging GmB, Germany.