

Spatial Data Mining in Conjunction with Object Based Image Analysis

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Abstract—The frequently changing spatial information are important because of their practical uses in various applications including disasters monitoring, deforestation, land management, planning, damage assessments and urban expansion. The wealth of geographic data cannot be fully evaluated when information inherent in data is difficult to differentiate. In remote sensing (RS) applications, changes are considered as surface component alternations with varying rates. This requires new approaches and tools that can be judiciously and automatically transform geographic data into information and capable for extracting geographic knowledge. A large number of change detection methodologies and techniques have been developed. In this paper, most common pixel-based techniques are described with the recent object-based techniques with similarities and differences between both the techniques. We also discussed the concept that can effectively detect spatio-temporal patterns in remotely sensed images following object based image analysis and data mining techniques. With the increased availability of very high spatial resolution RS data recently, the mining of such data calls for object-based techniques for potential change detection studies.

Index Terms—Remote Sensing, Spatial Data Mining, Change Detection, Object-based techniques

1 INTRODUCTION

THE central goal of most technical research in remote sensing is to improve a set of procedures for the extraction of information on resources from existing digital data. Remote sensing deals with the activities of recording (**sensing**) objects or events being far away (**remote**) places. Land-use and land-cover (LULC) change information is important in remotely sensed images for the reason that it is widely used in various applications. Change Detection (CD) analysis is used to identify, describe, and quantify differences between same scene images at different times or under different conditions. CD can be accomplished by traditional pixel-based approach or object-based approach. In pixel-based method, employing an image pixel as fundamental unit of analysis; whereas in object-based method, first creating image objects and then use them for further analysis. In this paper, various pixel-based and object-based methods are briefly described and compared. Several limitations of pixel-based techniques and why pixel-based approaches are not much suitable for Very High Resolution (VHR) remotely sensed images are described. We also describe how we can use object-based approach for change detection using Weka tools.

2 CHANGE DETECTION

There are two categories of change agents: a natural and biological action in nature and human activity among which the latter one is most notable factor. The CD frameworks use multi-temporal datasets to qualitatively analyse the temporal effects of change driving processes and quantify the changes. The RS data has become a foremost source for CD studies because of its wider selection of spatial and spectral resolutions,

synoptic view, digital format suitable for computation and more importantly high temporal frequency of coverage.

The basic principle behind using RS data for CD is that changes in the object of interest will alter the spectral behaviour (reflectance or local texture) that is separable from changes caused by other factors like atmospheric conditions, illumination and viewing angles. Applications of CD are forest or vegetation change, crop and flood monitoring, urban sprawl, landscape change, LULC change, fire affected area detection, coastal change etc. Before implementing CD analysis, some conditions must be satisfied by RS images. First is precise spatial registration of multi temporal images, second is the precise radiometric calibration or normalization for atmospheric effects between multi temporal images and last one is selection of the same spatial and spectral resolution images by same sensor system, if possible.

In CD, there are two types of knowledge for manipulation: (a) Context knowledge (about the context and objects there in when the image is acquired), and (b) Course knowledge (about what knowledge, when to use, how to use, etc.). Context knowledge includes:

- Object spectrum or varieties characteristic.
- Feature and evolution rules of spatial distribution
- Knowledge on models of sensors.
- Knowledge on objective geographical environment.
- Knowledge on imagery. Object property, spatial relation and association rules.
- Expert's interpretation knowledge.
- Geosciences auxiliary data.

CD process can be divided into: a) pre-processing, b) selecting CD technique, and c) accuracy assessment. Pre-processing stage deals with the corrections related to radiometric, atmospheric and topographic variations, geometric rectification and image registration. The selection of appropriate CD technique is based on objectives of study. The techniques such as image ratioing or differencing can only provide

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binary information (change/no change) while the detailed post-classification change matrix is required. Accuracy of CD can be improved by setting different thresholds for positive and negative changes. For identification of optimum threshold for change, we can either use manual method (trial-and-error) or automatic generation and testing. The first method is time consuming and labour intensive. Various algorithms are proposed for automatic threshold generation and [1] argued that the performance of these algorithms is scene-dependent. The CD process is shown in given Fig. 1.

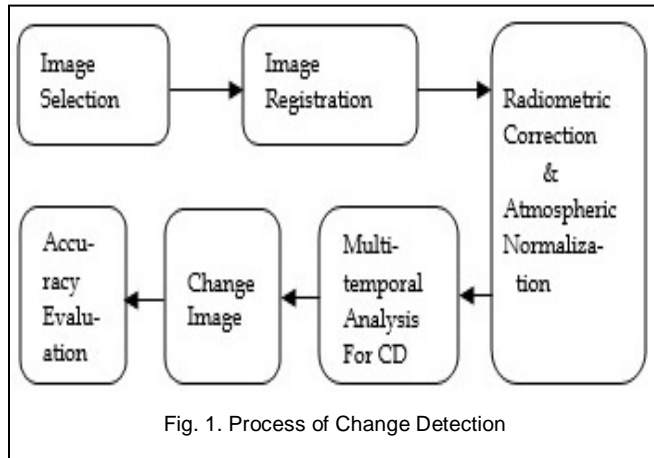


Fig. 1. Process of Change Detection

3 SPATIAL DATA MINING

Spatial Data Mining (SDM) is a developing research field. A spatial database holds objects which are tagged by a spatial location and/or extension as well as by some non-spatial attributes. SDM is the process of discovering interesting, non-trivial and useful patterns from large spatial datasets. Spatial data mining has both traditional spatial analysis fields (such as spatial statistics, exploratory data analysis and analytical cartography) and various data mining fields in statistics and computer science (such as classification, clustering, association rule mining, visual analytics and information visualization). The knowledge discovery process for spatial data is more complex than that for relational data and it affects both the algorithm's effectiveness as well to the complications of possible patterns that can be found in a spatial database, for the reason in contrast to mining in relational databases. An algorithm of SDM has to ruminate the neighbours of objects in demand to extract useful knowledge. There is a necessity of it as the attributes of the neighbours of some object of interest may have a potential influence on the object itself. The spatial data have a tendency to be highly correlated due to adjacency effects. Hence, the objective of SDM is to systematise the discovery of such correlations, which can then be examined by specialists for further verifications.

Geospatial Data Mining (GDM) is the sub-field of SDM. Geospatial data has two characteristics. The first one is that geospatial data repositories tend to be very large which is relevant to data mining/ knowledge discovery. The second one is that phase of data (data collected at high temporal frequency) should be extremely short, which are collected cyclically.

4 PIXEL-BASED CHANGE DETECTION (PBCD)

This is known as traditional approach because a pixel has been the elementary unit of image formation and hence the basis of analysis and CD techniques as in RS data. An image pixel is the miniscule analytical unit in these techniques whose spectral characteristics known as signatures are exploited to identify and measure changes typically without considering the spatial context. Pixel-based approach has many techniques, which differs by their sub-class techniques, viz. direct comparison, image transformation, classification based change detection, machine learning, Geographic Information System (GIS) and advanced methods. All the techniques are briefly described below with their benefits and limitations.

The first pixel-based approach is based on direct comparison of pixel's signature and this approach includes three different techniques named Image Differencing, Image Rationing and Regression Analysis. The first technique, Image Differencing in which images of the same area are obtained from times t_1 and t_2 and are subtracted pixel wise. This technique is straightforward, easy to implement and interpret and robust. The limitations of this technique are, (i) it works only if images are registered, (ii) cannot provide detailed matrices of CD, (iii) selection of suitable image bands and threshold; (iv) only positive and negative values are interpretable (Binary) and (v) requires atmospheric calibration or normalization. The second technique is Image Rationing in which ratio between two co-registered images is computed. It may lessen problems of viewing conditions especially sun angle. The limitations of this technique is that, it scales changes according to a single date, (I.e. $20/100=0.2$, $100/20=5$) and cannot provide detailed matrices of CD. The third technique, Regression Analysis, is one in which the I_2 image (at time t_2) is assumed to be a linear function of the I_1 image (at time t_1). Under this assumption, we can find an estimate of I_2 by using least-squares regression. The main benefit of this technique is that it moderates impacts of sensor, atmospheric and environmental differences and limitations of this technique is that it does not provide change matrix, it requires development of accurate regression models and not good for detecting subtle changes [2].

The second pixel-based approach is based on transformation of pixels and this approach includes five different techniques, viz. Principal Component Analysis (PCA), Change Vector Analysis (CVA), Texture Analysis, Tasselled cap Transformation (Kauth Thomas-KT) and Vegetation Index (VI) differencing. The first, PCA, assumes that multi-temporal data are extremely correlated and change information can be highlighted in the new minimum correlated components. It uses either the covariance matrices or the correlation matrix to transform data to an uncorrelated minimum correlated set. The benefit of this technique is that it reduce data redundancy between spectral bands and highlights different information in the derived component. There are some limitations of this

technique like, it cannot provide a complete matrix of change class information, it requires determining thresholds to identify the changed areas and it is scene dependent. Thus, the CD results between different dates are often difficult to interpret and label. Second technique, CVA is a technique where multiple image bands can be analysed simultaneously. It helps analysing and classifying the change. Change Vector is calculated by subtracting vectors pixel wise, as in image differencing, magnitude and direction of the change vectors are used for change analysis. It has several benefits like it is able to generate detailed CD information, works on multi-spectral data and processes any number of spectral bands. The limitations of this technique include are it shares some of the drawbacks of algebra based techniques. It is difficult to classify LC change trajectories using this technique and firmly requires the RS data acquired of the same phonological period. Third technique is Texture Analysis, in which change is measured by comparing the textural parameters from images. In this, the image is normally divided into smaller windows, after that texture is calculated and comparison is done at window level. With the help of this technique, it is possible to measure relative frequency of the spatial adjacency but the only drawback of this technique is that it is dependent on window size. The next technique is Kauth Thomas (KT) which is similar to PCA some difference. The PCA depends on the image scene where as KT is independent of the scene. Output features of KT represents are the greenness, brightness and wetness. It helps in reducing data redundancies between bands. Limitations of this technique are that it requires accurate atmospheric normalization, cannot provide a complete CD matrix and difficult to interpret and label change information. In VI, the second-date VI is subtracted from first-date Vegetation Index (VI). Different VIs has been developed, named ratio based, orthogonal indices and Soil Adjusted VI (SAVI). It highlights differences in spectral response of different features and reduces influences of topographic effects and illumination. Only positive and negative values (Binary) are interpreted and random or coherence noise is the limitations of this technique.

The third pixel-based approach is based on classification and this approach includes two different techniques named Post classification comparison and multi date direct comparison. The post classification comparison incoherently classifies multi-temporal images into thematic maps and implements pixel by pixel comparison of the classified images. It gives complete matrix of change information and minimizes impacts atmospheric effects, sensors and environment differences between multi-temporal images. This technique has some limitations such as, it needs a great amount of time and expertise to produce classification products and final accuracy hinges on the accuracy of the classified image of each time. Multi date direct comparison is a semi-automated approach that produces single analysis for multi-date datasets. This technique has two benefits that error rates are not cumulative

and atmospheric corrections are not required. When this technique is used, there are problems of labelling the change classes and hence in getting a complete CD matrix.

The fourth approach is with integration with GIS and it provides a base for data integration, visualization, and analysis and map construction. It integrates past and current maps with topographic and geological data. The binary masking and image overlaying methods are beneficial in revealing the change dynamics quantitatively. The only benefit of this technique is that it permits integration of aerial photographic data of existing and past LU classes with rest of the map data. Limitations of this technique are, classification system degrades the quality of results and different GIS data comes with different geometric accuracy.

The fifth approach is Machine Learning and it consists of three different techniques, viz. Support Vector Machine (SVM), Decision Tree (DT) and Artificial Neural Network (ANN). The first technique SVM is a non-parametric model that can handle small training datasets. Kernel function plays important role. It produces higher classification accuracy in comparison to traditional methods. The computational time required for classification and achieving optimization during the learning phase increase in polynomials with the increase in the data dimensions [3]. It is difficult to choose best kernel function for particular dataset. These are the two imitations of this technique. The second technique DT is also a non-parametric model that produces a tree that is easy to understand. It provides rule set for binary classes. If DT grows much larger in size, then makes it is challenging to interpret. The third technique ANN uses the back propagation algorithm to train the multi-layer perceptron of neural network model. It estimates the properties of data based on the training data samples. Limitations of this technique are, long training time required vital and large number of training data samples required for teaching the network and ANN functionalities not common in IP software.

The last and sixth approach is Spectral Mixture Analysis. It uses spectral mixture models to derive fraction of images. The fractions have biophysical significance in terms of the areal proportion of each end members within the pixel. The quantitative changes are measured by classified images based on the end member functions. The results are stable, accurate and reproducible. This is the benefit of this technique but up to some extent complex and time consuming.

5 LIMITATIONS OF PIXEL-BASED APPROACH

Presently, it is been gradually recognized that the demand from the RS community and their patrons of ever faster and more accurate classification results is not fully met due to different characteristics of HR images [4]. New VH-resolution sensors data meaningfully increase the within-class spectral variability and hence decrease the potential accuracy of a purely pixel-based approach to classification. Therefore, pixel-

based CD techniques' outcomes are often restricted when applied to very HR images. Very VHR image encompasses larger reflectance variability in each class (cause the salt and pepper effect resulting in decrease in the accuracy of pixel-based CD approaches) [5]. The spatial aspects, arrangements and their relationships are not exhibited in pixel-based analysis. The difficulty in modelling the contextual information is one more limitation of this approach. Pixel-based image analysis algorithms are either complimented or replaced by new methods because pixel-based methods point to noisy outputs like isolated changed pixels, holes in the connected changed components or uneven boundaries. The object based image analysis techniques are expected to overcome these drawbacks.

6 OBJECT-BASED CHANGE DETECTION (OBCD)

Object based image analysis (OBIA) includes older segmentation theories in an initial but essential step while further applying spatial concepts to developing image-objects and radiometric analyses that are earth surface centric. [6] argued that Geographic space is intrinsic to this analysis, and as such, should be included in the name of the concept and, consequently, in the abbreviation: "Geographic Object-Based Image Analysis" (GEOBIA). Only then it is clear that we refer to a sub-discipline of Geographic Information Science (GIScience).

Groups of pixels in an image make image-objects which characterize significant objects in the scene. The unit for analysis in the object based approach is an image object which gets clearly defined by incorporating information on texture, shape, and spatial relationships with neighbouring objects and ancillary spatial data at different spatial resolutions ([7]; [8]) allowing the exploration of the spatial context. Based on the concept of image-objects and the definition of change by [9], [10] defined OBCD (Object Based Change detection) as "the process of identifying differences in geographic objects at different moments using object based image analysis". The purpose of OBIA is to ensure that the image classification and the results are crisp and discrete. These types of classification results are beneficial for thematic analysis and CD studies. The OBIA based classification usually encompasses: a) Image Segmentation, b) Object Hierarchy development (based on training dataset) and c) classification ([11]; [12]). To extract patterns from an image, the segmentation algorithms are used. Segmentation of an image is simply partitioning of an image into homogenous objects such that they are spectrally identical and spatially adjacent [13].

Most of the segmentation methods can be grouped into either boundary or edge-based (discontinuity of pixels) or area-based (resemblance of pixel values) techniques ([14]). Segmentation method also includes a third group named "threshold based segmentation". [10] grouped them into four different change detection techniques. All the techniques are briefly described below with their advantages and limitations.

The first techniques is based on direct object comparison, in which objects extracted from one image are assigned to an object from or searched from image data from second acquisition. It is similar to pixel-based approach and as per the name, it directly compares two or more image objects from different dates for CD. CD can be performed either by comparing spectral information (from multi-temporal images, segments are extracted and compared) or by comparing the geometrical properties (an object from one image is extracted or assigned from another image without segmentation). Change is linked to the objects extracted exclusively from the first image and will not deliver new objects that might be created in the second image. This is the drawback of this second approach. This technique has some advantages that it can be easily integrated with GIS, implementation is easy due to direct comparison of objects and the change detection can be done by spectral or extracted spatial features. At the same time it has several limitations such as suitable selection of thresholds is amount when objects are compared based on spectral features and shapes are, unable to provide from-to change matrix and reliant on accuracy of the segments.

The second technique is based on object classification comparison, in which two segmentations created separately and compared for CD. It is the most used technique of OBCD that is performed on multi-temporal images. It extracts the objects from images and independently classifies them. And for detailed change analysis, these classified objects are compared. This method permits for thematic, topological and geometric change measures. It provides from-to change matrix, result is based on classification comparison and all available objects are used for CD. It has some limitations too, like it is reliant on accuracy of the segmentations. Classification accuracy affects the CD accuracy, sometimes gives incorrect results when location errors are involved (when objects extracted from one image is been searched in another image at that time location error occurs) and due to segmentation of multi-temporal images, difference occurs in size and correspondence of image objects.

The third technique is based on multi-temporal object CD, in which Image segmentation and classification are directly applied to composite or stacked multi-temporal images and extracted objects are assigned spectral values from each of the different date images. The composite image may be comprised of one or more co-registered multi-spectral, texture and/or panchromatic multi-temporal images. This technique has two advantages viz. derived features to create change trajectories and objects have equal geometric properties by two times. The limitation of this technique is that different objects are created at different times because of change.

The last and fourth technique is Hybrid Change Detection (HCD). Basically HCD are categorised as procedure-base or result-based techniques where procedure-based techniques uses different detection methods for different detection phases and result-based techniques uses different CD methods for analysing results. It remains unclear how the final change results are influenced by the different combinations of pixel-based and object-based schemes [10].

7 LIMITATIONS OF OBJECT-BASED APPROACH

Object-based image analysis techniques basically assume that objects derived through segmentation of an image resembles to objects at the surface level. However perfect on-to-one correspondence may not be possible in all instances, mostly when the resolution of the image is very coarse or the object is small [15]. The object geometries are determined by selected segmentation algorithm and that needs specific solutions to preserve the reliability and consistency in connecting the objects extracted at two different times. This image segmentation process also suffers from under-segmentation and over-segmentation errors. Under-segmentation and over-segmentation reduce the classification accuracy as both create objects that may not represent the properties of objects on the ground. Challenges similar to pixel-based approach like training set size and its completeness are also faced by OBIA techniques because of the image objects are first extracted and then classified using various pixel-based supervised and unsupervised classification algorithms. In OBIA, object extraction is spatial resolution dependent. The extracted objects differ in their conceptualization between genuine (perceptible and observable in the ground) and false (deficient a physical border).

8 SIMILARITIES AND DIFFERENCES

In this section we describe similarities (TABLE 1) and differences (TABLE 2) between different techniques of pixel-based and object-based approach for CD.

9 DATA MINING TECHNIQUE AND CHANGE DETECTION

The construction of an image interpretation model, simply called knowledge discovery/model is the most important phase and one which is often difficult to execute, since the experts may lack an exact notion as to what are the best descriptive attributes of the objects that must be classified [17]. So some experts state in their articles that to enable automatic generation of a structure of knowledge is to adopt Data Mining (DM) techniques [18]. We can call this combined one as Object based Image Analysis + Data Mining (OBIA+DM) concept.

DM is a distinct stage within the process named as Knowledge Discovery in Databases (KDD), which involves application patterns of information and algorithms and techniques used for extracting knowledge. DM algorithms and techniques are used for extracting non-trivial and implicit in-

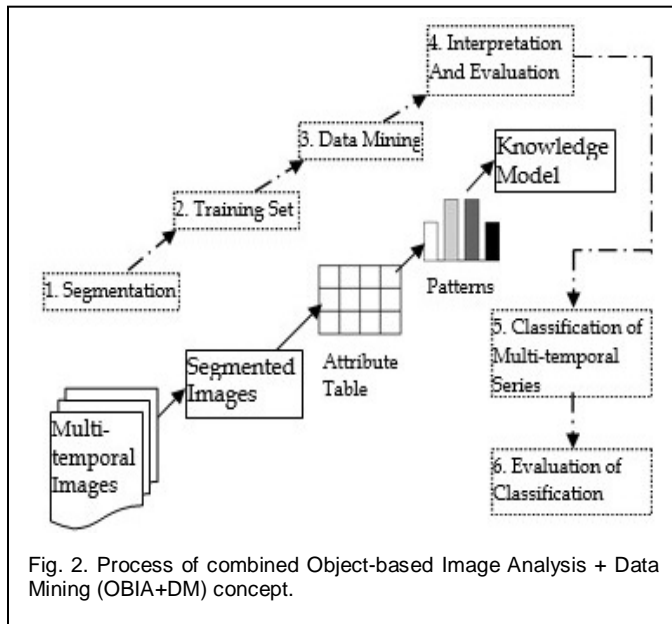
TABLE 1
SIMILARITIES BETWEEN DIFFERENT TECHNIQUES OF PIXEL-BASED AND OBJECT-BASED APPROACH FOR CD

Pixel-based approach	Object-based approach
In pixel-based technique, a direct comparison between pixels from different dates is performed for CD	DOCD technique of object-based approach, a direct comparison between objects from different dates is performed for CD
Classification-based CD technique named post-classification comparison, the final performance accuracy is dependent on classification accuracy of individual images	COCD technique of object-based approach, the final performance is dependent on the accuracy of the classification algorithm

TABLE 2
DIFFERENCE BETWEEN DIFFERENT TECHNIQUES OF PIXEL-BASED AND OBJECT-BASED APPROACH FOR CD

Pixel-based approach	Object-based approach
Machine learning techniques like ANN, SVM and DT of pixel-based approach uses classification algorithm that produce only binary (change Vs. no change) matrix as a result of CD	COCD object-based approach uses classification algorithm that produce from-to (detailed) matrix as a result of change
Pixel-based techniques have no need of segmentation algorithms	Object-based techniques have need of segmentation algorithm to partitions an image in to homogenous objects
Direct multi-date classification technique of pixel-based approach is used to detect changes from stacked multi-temporal images but the temporal and spectral features have equal status in combined dataset so it will make difficult to separate the spectral change within one multispectral image from temporal changes between images in classification [16]	MOCD technique of object-based approach is used to detect changes from stacked multi-temporal images but single segmentation of stacked images results in creating image objects consistent in size, shape and location coordinate over time and it will also not provide different/new objects that might be created at different times because of change

formation leading to building a knowledge model. Fig. 2 depicts how OBIA+DM are integrated.



This OBIA+DM approach is interactive, iterative, exploratory and cognitive which includes following stages: image segmentation, training set generation, data mining, interpreting and evaluating the classification techniques and validating the classification on independent samples. In image segmentation stage, the image segmented using different algorithms. In this stage, the basic processing unit, objects, are generated through segmentation algorithm. In next stage, for building training set two or more classes of interest are defined and for each class sample objects are selected with the help of an expert of the object. After having built training set, attributes are extracted from most interested classes. Those extracted attributes may have spectral, spatial or textural characteristics. The next stage is DM that involves application of intelligent techniques in order to extract patterns of interest for effective knowledge production. The interpretation and evaluation of knowledge in each class patterns is interpreted and evaluated in order to build the best knowledge model. The classification stage of multi-temporal data will be active after training and evaluating the knowledge model. In this stage, the extracted object attributes from multi-temporal series of data are classified to map changed areas. And in the last stage named evaluation of classification (classification accuracy assessment) is to be done. One reason for adopting this combined concept is that it allows the evaluation of the whole classification process including the very first segmentation stage.

8 CONCLUSION

The main objective of this paper is to explore the effectiveness of integrated OBIA+DM (Object-based Image Analysis + Data Mining) concept. Change Detection (CD) from remotely sensed spatial data is a topic of ever growing interest. We here briefly described the concept of CD for remotely sensed spatial data. We have presented different pixel-based and object-

based techniques with their brief description and benefits. We have also described the limitations of both approaches and concluded that even though the traditional pixel-based techniques have been, and remain, an important research subject and are successfully implemented in many areas to measure CD using Remotely Sensed (RS) data, but they are less suitable for handling the large variations in Very High Resolution (VHR) remotely sensed data. The object-based approach is best suited and powerful for modelling conceptual information in remotely sensed CD process and is also capable of handling large variations in VHR RS data. Higher accuracy and improved results are achieved with the use of object-based approaches in compared to pixel-based approaches.

We have presented a combined concept of OBIA+DM that can effectively detect spatio-temporal patterns available in remotely sensed images for several applications including change detection process. With the help of advanced classification and clustering techniques of DM, we can improve them. The classification results and object-based concept are used in exploring different characteristics of the complex relationships in the data normally hidden from the analysts.

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