An application of object-based analysis of satellite imagery on waste

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Abstract. Traditional image processing and image interpretation methods are usually based only on the information extracted from features intrinsic of single pixel: the object's physical properties, which are determined by the real world and the imaging situation - basically sensor and illumination. A limitation of this method is that it allows to evaluate only a part of the information content of the images, without exploring the appearance as important as geometric-textural information. The application of Object Based Image Analysis on very high resolution data allows, with an automatic or semi-automatic process – with a minimal manual participation - a good classification also in presence of high and very high resolution data, where higher is the chance of error. The final classification, through a suitable hierarchy of classes that takes into account the relationships between the produced segmentation levels, may be highly accurate. Thus we introduce other rules for the location of the context, and the relations between the objects meaningfully increases the chance of automatic recognition of objects on the land surface. The availability of object-based techniques allows an elaboration of satellite data to detect situations of illegality as the uncontrolled storage of waste. Through the inclusion in the segmentation process of a shapefile containing some detected test areas, we proceed to the recognition of the landfill areas. In this work we also use some cadastral data for multiresolution segmentation and object-based classification.

Keywords. Object Based Image Analysis, Satellite Imagery, Illegal dumps, Multiresolution segmentation.

1. Introduction

Among the threats that endanger the environment and health, illegal rubbish dumps impact heavily on the landscape and environment and are a danger for the health and safety of citizens and inhabitants, The activity of land monitoring is also reflected in the recognition of the abuses relating to uncontrolled storage of waste and the use of satellite remote sensing images helps to improve the environmental management. Such situations of illegality can be detected thanks to the availability of object-oriented techniques for processing satellite imagery.

The research proposed here is still in progress in order to refine the techniques already employed but it raises the possibility of an application of the same methods in other contexts.

Soil is a system very complex, crucial to the ecological balance, which includes a number of issues of environmental relevance.

European legislation has long established monitoring the component soil, particularly landfills. Directive 91/689/EEC determined that all companies have signed up about the development of hazardous waste but Italy had not yet adopted legislation to implement it. In 2001, the European Commission imposed sanctions against Italy for the lack of data on landfills in its territory.

In Calabria, as well as in the rest of Italy, soil is directly related to management of contaminated sites and waste and environmental emergencies. In particular, in Calabria for many years was declared a state of emergency in the area of municipal, special and hazardous, so a special commissioner was appointed to manage this sector.

All this is despite there has not been the strong industrial development in Calabria than in other regions has led to soil pollution; here, limited and messy, often without proper planning, a real sprawl has struck many "wounds" to the territory.

There is no data derived from surveys of landfills, in particular those containing hazardous and toxic waste.

2. Methods

This paper uses remote sensing data and image analysis techniques to monitor structural landfills potential. The purpose of this paper is to illustrate an application of Object Based Image Analysis on very high resolution data, particularly on the IKONOS multispectral images of Melito di Porto Salvo, in the province of Reggio Calabria, with the aim of showing how the analysis automatic - with minimal manual intervention - can facilitate the recognition of landfills.

2.1. Object Based Image Analysis

Two are the object-based techniques that distinguish structural methodology from classic spectral analysis: multiresolution segmentation and classification segmentation-based. The tool used organizes hierarchically data of different typology, integrating also raster and vector data. The context has a role and it is possible to introduce rules for the location of the objects and to define their relationships, meaningfully increasing so the possibility of a quick and automatic acknowledgment of the objects on the land surface. Such methodology, by imitating the approach followed in manual photo interpretation, exceeds the limits of a subjective classification by making a process that can be reproduced and homogenous, and so exceeds the problems of the traditional classification techniques. The parameter of scale factor allows to calibrate the width of the resultant polygons, and its definition is tied to the cartographic scale reference that the customer must obtain. Beginning from a same image, is possible to generate various hierarchical levels of polygons with various scale factors, therefore the segmentation process is multiresolution. With object-based analysis is possible to get better from remote sensing an information immediately integrated in the GIS allowing the direct realization of vector maps.

The object based approach is characterized by a circular interplay between processing and classifying image objects. Based on segmentation, scale and shape of image objects, specific information is available for classification. Classification, incorporating contextual and semantic information that utilizes not only image object attributes but also the relationship between networked image objects, resulted in an operational classification model. In many applications the desired geoinformation and objects of interest are extracted step by step, by iterative loops of classifying and processing. Image objects as processing units can continuously change their shape, classification and mutual relations. Similar to human image understanding processes, this kind of circular processing results in a sequence of intermediate states, with an increasing differentiation of classification and an increasing abstraction of the original image information – the pixel value, that brings a semantic low level information, as the amount of energy emitted while the context does not assume any role.

In the object oriented analysis the semantic level raising: relation rules join space, topological information and statistics are added so the context is defined. Recognition is based on concepts of Mathematical Morphology applied to the image analysis and, for classification, elements of Fuzzy Logic. In the example, the tool operates a segmentation of the entire scene on more levels.

2.1.1. Multiresolution Segmentation

Multiresolution Segmentation is a bottom up region-merging technique starting with one-pixel objects. Smaller image objects in subsequent steps are merged into bigger ones. The underlying optimization procedure of this clustering process 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, multiresolution segmentation is a local optimization procedure.

The sum of the standard deviations of spectral values in each layer weighted with the weights for each layer are Spectral or Color heterogeneity:

$$h_s = \sum_{c=1}^{q} w_c \sigma_c \qquad (1)$$

where:

h_s is spectral heterogeneity;

q = bands number;

σ_c = standard deviation of *digital number* in c spectral band;

w_c = weight assigned to c spectral band.

The exclusive minimization of spectral heterogeneity leads to branched segments or to image objects with a fractally shaped borderline. This effect is even stronger in highly textured data, such as radar data.

For this reason it is useful in most cases to mix the criterion for spectral heterogeneity with a criterion for spatial heterogeneity, in order to reduce the deviation from a compact or smooth shape. Heterogeneity as deviation from a compact shape is described by the ratio of the border length l and the square root of the number of pixels forming this image object.

$$h_{g\_smooth} = \frac{l}{\sqrt{n}} \qquad (2)$$

where:

h_{g_smooth} = fractal factor of spatial heterogeneity;

l = border length;

n = number of pixels of the image object.

The second is a compactness f*actor* ($h_{g\_compact}$) that depends from dimensional ratio of polygon axis:

$$h_{g\_compact} = \frac{l}{b} \qquad (3)$$

where:

$h_{g\_compact}$ = compactness factor; l = berder length;

b = the shortest possible border length given by the bounding box of an image object parallel to the raster.

The segmentation algorithm proceeds fusing adjacent polygons beginning from every pixel of the image until the change of observable heterogeneity between the two original polygons and the new generated polygon does not exceed the threshold defined from the customer (scale factor). If the change of heterogeneity already does not exceed the threshold defined the fusion is effectively realized, otherwise the two polygons remain separated. Heterogeneity difference (overall fusion value) between resultant object and the two original polygons is:

$$f = w_f \Delta h_s + (1 - w_f)\Delta h_g \qquad (4)$$

where:

f = *overall fusion value*;

w_f = the user defined weight for color (against shape).

The choice of the scale factor allows to calibrate the largeness of the resultant polygons, and its definition is tied to the cartographic scale reference that the customer must obtain. A reduction of the scale factor the polygons generated become more and more small because smaller it must turn out the spectral variability intra-polygons, and whereas increasing the scale factor.

2.1.2. Segmentation Procedure

Connection between the polygons of the various hierarchical levels of the segmentation is a particularity of the multiresolution. As a first level of polygons is generated is possible to generate n new upper hierarchical levels (if the scale factor is larger - greater polygons) or n inferior levels (if the scale factor is smaller - smaller polygons).

Polygons of inferior hierarchical level are always geometrically consisting with those of upper hierarchical level, so every polygon of inferior level only belongs to one polygon of upper level. Every polygon therefore “knows” the polygons in contact on the same hierarchical level, the polygons that constitute an inferior hierarchical level and the polygon in which it is contained in the upper hierarchical level.

2.1.3. Fuzzy Classification

Fuzzy logic is a mathematical approach to quantifying uncertain statements. Instead of the two strictly logical statements “yes” and “no” Fuzzy logic uses the continuous range of [0…1], where 0 means “exactly no” and 1 means “exactly yes.”. All values between 0 and 1 represent a more or less certain state of “yes” and “no”.

Fuzzy sets, more recently, have been employed in the classification of land terrain covers [1]. Fuzzy sets theory [2], which has been developed to deal with imprecise information, can provide a more appropriate solution to this problem. It provides, indeed, useful concepts and tools to deal with imprecise information. It allows each region to have partial and multiple membership in several classes. A region’s membership grade function with respect to a specific class indicates to what extent its properties are akin to that class, and the value of the membership grade varies between 0 and 1. Closer the value is to 1 more that region belongs to that class. Partial membership allows that the information about more complex situations, such as intermediate conditions or cover mixture, can be better represented and utilized.

Fuzzy logic emulates human thinking and takes into account even linguistic rules. Fuzzy classification systems are well suited to handling most vagueness in remote sensing information extraction. Parameter and model uncertainties are considered as using fuzzy sets defined by membership functions. Instead of the binary “true” and “false” multivalued fuzzy logic allows transitions between “true” and “false”.

There are more or less strict realizations of the logical operations “and” or “or”.

The output of a fuzzy classification system is a fuzzy classification, where the membership degree to each land cover or land use class is given for each object. This enables detailed performance analysis and gives insight into the class mixture for each image object. This is a major advantage of soft classification. The maximum membership degree determines the final classification to build an interface to crisp systems.

A fuzzy rule base is a combination of fuzzy rules, which combine different fuzzy sets. The simplest fuzzy rules are dependent on only one fuzzy set.

Fuzzy rules are “if – then” rules. If a condition is fulfilled, an action takes place. Referring to fig. 8, the following rule could be defined: “If ” feature x is low, “then” the image object should be assigned to land cover W. In fuzzy terminology this would be written: “If feature x is a member of fuzzy set low, then the image object is a member of land cover *W*”.

To create advanced fuzzy rules, fuzzy sets can be combined. An operator returns a fuzzy value that is derived from the combined fuzzy sets. How this value is derived depends on the operator.

The higher the return value for the most possible class, the more reliable the assignment. In the example above, the membership to water is rather high and in most applications this object would therefore be assigned to the class *Water*. The minimum membership value an object needs to have in order to be assigned to a class can be defined.

Fuzzy classification with its enhanced analysis of classification performance of class mixture, classification reliability and stability is possible, because fuzzy classification is one powerful approach to soft classification. The results of the fuzzy classification are an important input for information fusion in current and future remote sensing systems with multidata sources. The reliability of class assignments for each sensor can be used to find the most possible class assignment. A solution is possible, even if there are contradictory class assignments based on different sensor data.

3. Results

The case concerns the recognition of landfills in the area of a town in Calabria (Melito di Porto Salvo, located in the province of Reggio Calabria). The data available are satellite images Ikonos of the year 2002, georeferred to WGS84 (WGS84 Datum, UTM 33 North); there are added some cadastral information, brought in vector format with the same reference system of the satellite data.

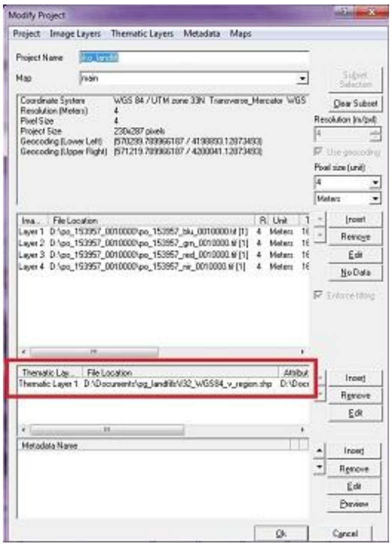

Figure 1. Creation of a project, Ikonos image and the shapefile with cadastral parcels.

The aim is to segment a first time the area with first objects created matching with the cadastral polygons, acquiring their attributes. For this purpose, in the chessboard segmentation will be assigned a scale factor very high for avoiding the risk that the parcels found to split in them.

Figure 2. The first segmentation creates objects matching cadastral parcels.

Obtained objects, the subsequent operation is the realization of a classification based on two different values of the attributes of the given parcels and, then, of the objects created. The parcels, which header show the property, in this case are simply divided by holder in "public" and "private". This simple distinction when are identified illegal dumps would enable agencies to initiate penalty proceedings or recovery in these two different cases.

We then proceed to a separate classification for "public" and "private" that will serve only as an internal procedure.

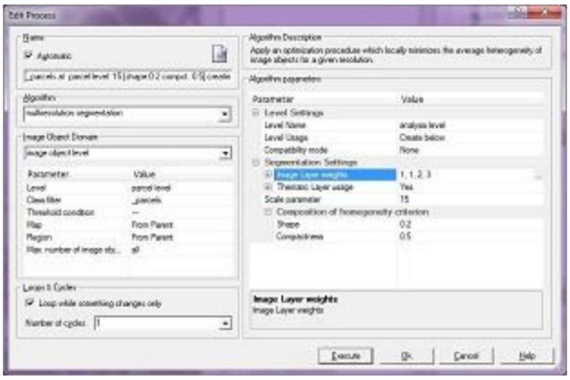

Figure 3. Multiresolution segmentation analysing the standard deviation (pixel variability), assigning higher weight to IR and red bands.

Above is a multiresolution segmentation based on previous classification, that will be used to achieve a level of analysis. Are assigned different "weights" to infrared and red bands than the other so as to make them more significant on segmentation, where the shape parameter is 0.2 (so that for the color increases to 0.8) while the factor of compactness is set at 0.5, the scale factor is 15, so we get objects small enough to represent the various differences in emission of materials on the soil.

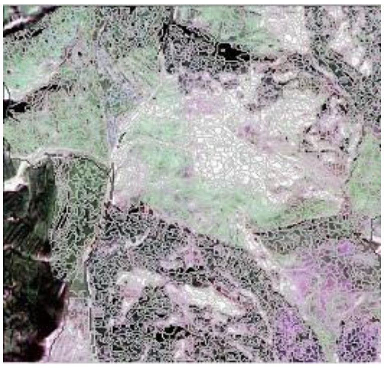

Figure 4. Result of the multiresolution segmentation with different weights to bands.

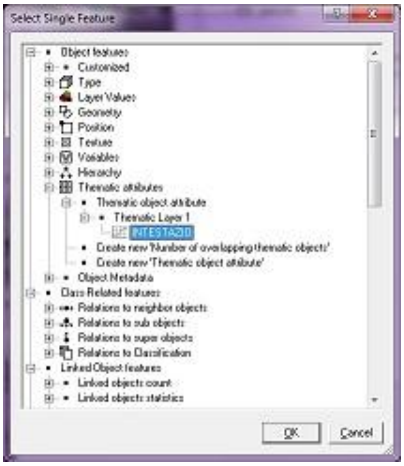

Figure 5. In classification segmentation-based the attributes of the cadastral layer.

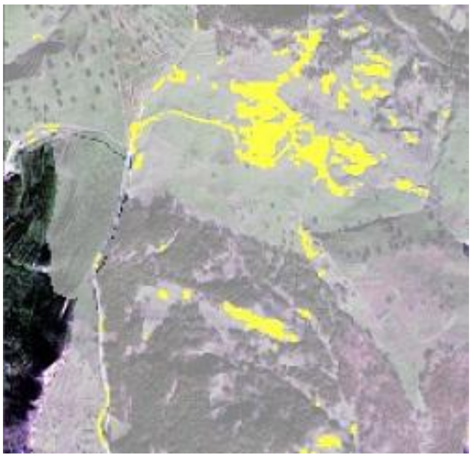

Figure 6. Potential Landfills (yellow).

The next classification transferred to these small objects the properties of super-object, ie. the land parcels.

Following appropriate assessments of some values of pixel variability - in fact, in landfills are extremely heterogeneous materials - are identified with the classification some areas where may be landfills (Potential Landfills), in yellow.

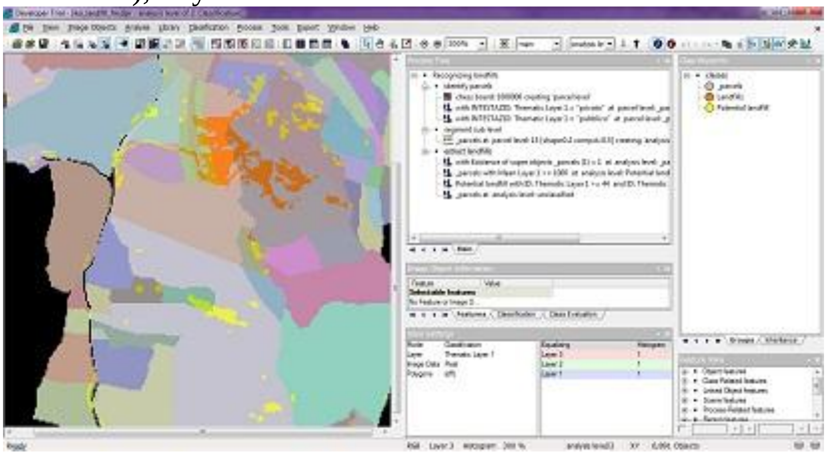

Figure 7. Cadastral parcels and classification of landfills (orange).

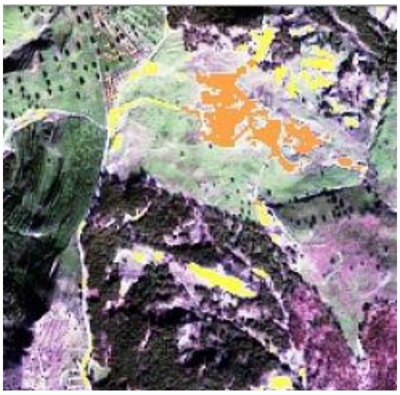

Figure 8. “Potential landfills” and “Landfills”, removing the ‘_parcel‘ classification.

Finally, with a further classification we will specify the areas most affected by these values (Landfills), which actually correspond to the areas affected by an old landfill operated by the municipality in the year of reference image.

Last step is the reallocation of "unclassified" objects that do not fall within the Landfills.

4. Conclusions

In the near future we should treat all types of waste but the reality is still different: today there are always new illegal dump sites.

In this project the use of remote sensing is functional and effective as it allows for monitoring, with regular purchasing of satellite imagery.

Remote sensing data, survey and inventory could then be supported by available data from local authorities for their respective territories and together could flow in a spatial database regularly updated also with satellite imagery.

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