Accuracy Assessment of Per-Field Classification Integrating Very Fine Spatial Resolution Satellite Imagery with Topographic Data

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Abstract

The paper describes an automated system for classifying land use on a local scale, integrating remote sensing and GIS data, with an aim of extracting meaningful information for performing spatial analysis in urban contexts. First, the background in the extraction of contextual information from fine spatial resolution satellite imagery in an integrated RS/GIS system is considered in detail. Then, a per-field classification technique is described. After that, the assessment of classification accuracy is discussed with regard to the nature of the problems emerged in the procedure. The per-field classification technique was applied to an IKONOS multispectral image with spatial resolution of 4m by utilising a digital topographic map and the classification accuracy is also reported.

1 Introduction

The information contained in digital imagery, acquired by Remote Sensing technology, can be used for mapping, monitoring and assessing the properties of the environmental and territorial feature elements. Of all these three main application fields in Remote Sensing, making thematic cartography by means of automatic classification methods is surely the most widespread one and in many cases is an essential preliminary step for further applications.

So far, it has been proved that spatial resolution of data given by earth observation satellites is inadequate in providing detailed topographic peculiarities, in specific application domains of analysis and monitoring of urban environment. Modality of terrestrial phenomenon representations, augmented geometric accuracy, temporal flexibility of acquisition, spatial land cover and appropriate use in spatial modelling suggest, instead, the diffusion and continual use of very fine spatial resolution satellite imagery which is newly available, as data sources for spatial analysis in urban contexts. Indeed, planners' activities can be better supported by high-resolution remote sensing and its interaction with other disciplinary sectors, because, as Mesev et al. (1996) have argued, "our concern with land use revolves around the central 'urban/non urban' dichotomy as manifest through physical form, although in practice finer disaggregations as well as measures of the intensity of human activities are also desirable".

The informational classes of a thematic mapping are not directly registered, but must be derived indirectly by using evidence contained in the spectral data of an image. When we apply standard procedures of per-pixel multispectral classification, the increase of spatial resolution leads to augmentation in ambiguity in the statistical definition of land cover classes and a decrease of accuracy in automatic identification. This problem may be overcome by means of per-field classification techniques which involve analysing groups of pixels within land cover parcels. Such technique, based on the integration of remotely sensed imagery and digital vector data, has been used to generate land cover and land use information for more than a decade (Carbone et al. 1996; Ehlers et al., 1991; Hinton, 1997). Innovation and power of recent GIS platforms and analytical flexibility of image processing software make the integration of satellite data with numerical and scaled topographic data much more feasible. And this can lead to an increase in accuracy of the classification compared with the per-pixel technique, as well as improvements in interpretations of results with incorporating spatial variability and texture inherent in fine spatial resolution imagery.

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This paper describes a per-field classification methodology. It has been applied to an IKONOS multispectral image with spatial resolution of 4m by utilising a digital large scale topographic map as a representative reference land cover, and assesses the accuracy of classification by comparing the results carried out for both the per – pixel and the per–field techniques. Finally, the nature of problems emerged with both procedures is also identified clearly.

2 The Extraction of Contextual Information from Fine Spatial Resolution Satellite Imagery in an Integrated RS/GIS System

The accuracy with which land use has been mapped up to now from satellite sensor imagery from local to national scales has been limited by the relatively coarse spatial resolution of instruments. For example, for the land cover maps generated using Landsat Thematic Mapper (TM) imagery, with a spatial resolution of 30m, a considerable amount of details in a scene is obscured from the image. The availability of recent multispectral imagery with very fine spatial resolution has increased our ability to map land use in geometric detail and accuracy (Aplin et al. 1997) for local and national scale investigations.

However, these sources of imagery are likely to generate other problems. Even if the radiometric resolution is enhanced (11 bits for IKONOS imagery), spectral capabilities are generally limited compared to those of the previous generation sensors (seven bands for the Landsat TM). Moreover, associated with an increase in spatial resolution there is, usually, an increase in variability within land parcels (‘noise’ in the image), generating a decrease in accuracy of land use classification on a per-pixel basis (Townshend, 1992).

Traditional automated classification techniques classify land use on a basis of spectral distribution of the pixels within an image, whereby each pixel is associated with the most similar spectral class. This general method can produce results that are ’noisy’ due to the high spatial frequency of the land covers. Moreover, the popular classification algorithms are based on single pixel analysis, producing a geometric outline of land covers that does not correspond to real spatial entity representation (fields, roads or streams).

With an aim to solve such problems some post-classification procedures were investigated, on the basis of intrinsic contextual information of data (Thomas, 1980; Townshend, 1986). Although a reduction of noise in the classified image was obtained, it didn't make substantial improvements in overall accuracy of the results. Moreover, a loss of meaningful information in classified data was shown, because of geometric and dimensional non-correspondence of real elements with moving window implementation matrix (for example with *majority* logical filter). Such methods need extensive editing operations on classified images in order to be stored in GIS databases.

An alternative technique to per-pixel classification is the per-field classification (so called because fields, as opposed pixels, are classified as independent units), which takes into account the spectral and spatial properties of the imagery, the size and shape of the fields and the land cover classes chosen. In fact, this approach requires a priori information about the boundaries of objects in the image, for examples, road fields. If the boundaries of these fields are digitised and registered to the image, then some property of the pixel lying within boundaries of the field can be used to characterise that fields. For instance, the means and standard deviations in the four IKONOS bands of pixel lying within fields could be used as features defining the spectral reflectance properties of fields.

All these considerations suggest that replacing the coarser spatial resolution satellite sensor imagery with finer ones would lead to an increase in per-field classification accuracy, especially for relatively small sized fields (Harris and Ventura, 1995; Westmoreland and Stow, 1992).

High level of interoperability and flexibility achieved by the present RS/GIS systems allows integration and analysis of the two data models (raster and vector), by offering suitable statistical and logical instruments for specific applications fields (Hinton, 1997). However, the method used to integrate remotely sensed imagery with field boundaries is also meaningful. Such integration may be carried out in three stages (White, 1995):

a) before classification (pre-classifier stratification),
b) during classification (classifier modification);
c) after classification (post-classifier sorting).

Many examples of these procedures employ only the latter two. Westmoreland and Stow (1992) integrate, in a single stage, cartographic data with remote sensed imagery during classification to assess land use change on per-field basis. Alternatively, other studies obtain land cover on a per-pixel basis before integrating the classified image with cartographic data for per-field classification (White, 1995).

The positive effects of such techniques (*post-classifier sorting*) consist in the better overall accuracy of classified image and in the possibility to use regions with arbitrary or not predetermined dimensions and outlines, as in the case of conventional logical filters. Thus, these procedures produce the typical input for a GIS database: a set of spatial entities (regions) with attributes (for example land cover classes). Normally, the use of map and image data would take place within a geographical information system (GIS), which provides facilities for manipulating digitised boundary lines (for example, checking the set of line to eliminate duplicated boundaries, ensuring that lines 'snap on' to nodes, and identifying illogical lines that end unexpectedly).

The ways with which the two data models, raster and vector, are integrated in a RS/GIS system can be summarised in:

a) separate database, cartographic and image processing systems with facilities to transfer data between them;
b) two software packages (image processing and GIS) with a shared user interface and dynamic links;
c) a single software package with shared processing.

In this study the b) type of implementation is performed, because of the high level of the customisable statistical and logical tools and the possibility of modifying per-pixel classification using the spatial information derived from external data.

3 The Study Area and the Data Sources

This study area of this research is in Italian, i.e. part of the municipal district of Fasano (Brindisi) in the Apulia region (Figure 1). The size of test area is about

Figure 1 Color composite image of IKONOS data - Fasano (Italy)

4km × 5km). The area represents a critical area because of urbanisation over the last thirty years, (still continuing now). Such evolution is been apparent with long period built-up area phenomena on a local scale (second home), with rise and spread of tourist places ("Safari" zoo, fair grounds) and, finally, with agricultural transformations (olive-groves dominating over natural areas, such as ilex and Mediterranean bush).

The geomorphologic and settling features, with the town and the ancient fortified farms that are located on the plain (100 m a.s.l. quota) and the villas that are strewn around the hills (300-400 m a.s.l. quota), justify the choice of this area, because it permits the testing of the validity of well-established methodologies of classification on a over-regional scale, but barely investigated on new generation satellite sensors imagery. Moreover, such studies allow opening of new unexplored techniques applicable on a large scale by adding meaningful inputs to those multidisciplinary studies connected to decision-making and planning activities.

The data sources acquired for the analysis consists of:

a) raster data of spectral bands 1 to 4 of IKONOS scene (Acquisition Date/Time: 2000-05-12 / 09:14) processed using the remote sensing image processing system ERMAPPER;
b) digital topographic map in a scale of 1: 5000 (Date, 1998), stored and processed by means of the geographical information system ARC/INFO;
c) training set and the ground reference data obtained by land use survey (January 2001) and additional maps.

4 Data Processing and Accuracy Assessment

To facilitate the integration of the IKONOS and vector data it was necessary to register both data sets to a single map coordinate system (Mather, 1995), in this case Gauss-Boaga map projection and Roma40 datum, by identifying 30 common Ground Control Points (GCPs). A high (3rd) order transformation for rectification (RMS value lower than 1 pixel) and a nearest neighbour resampling method on the image were executed, in order to consider the relief of certain sub-areas and the minor distortion of radiometric values in the row data respectively (Khan et al., 1995).

In the next step of pre-processing phase image enhancement techniques were applied to emphasise details and to facilitate individuation of the selected training set. For this purpose, sharpening algorithms in an iterative way were implemented in order to transform the input matrix and to eliminate components with pre-established frequency threshold.

The spatial resolution of IKONOS image allowed individuation of nine land use classes (asphalt road, country road, arterial road, high density buildings, low density buildings, sown ground, uncultivated ground, Mediterranean bush, olive-grove).

Generally, remotely sensed reflectance is related to land cover and not to land use, but in the present case each land use class was assumed to correspond to spectrally separable land covers.

The selection of the more representative *training sets* was derived from the analysis of scatter diagrams and frequency histograms that show the degree of correlation between spectral bands and the frequency of raw data radiometric values. In this way better spectral identification of the classes was obtained, by correctly individualising also minor amplitude regions and obtaining acceptable results already in the first phase of procedure.

After this, the per-pixel classifier was trained on a representative sample of each of the land use classes by using a *supervised maximum likelihood classification* (MLH) algorithm with equal prior probabilities for each class.

This parametric classifier was selected because, by using the shape of the distribution of membership (represented by covariance) as well as the mean of the training data to identify each class, offered a very high general level of global accuracy.

As completion of this phase, first accuracy assessment of results on ground truth data was carried out, with the aim to determine the quality of information derived from remote sensed data

(Congalton, 1991) and to deduce meaningful indications on thematic correctness. The overall accuracy achieved by MLH classification was of 68%.

To perform classification accuracy assessment correctly and to ensure objectivity and consistency, it is necessary to compare two source of information: (1) the remote sensing derived classification map and (2) the reference test information kept independent of training data. The relationship between these two sets of information is commonly summarised in:

a) error matrix, which describes the comparison of two source of information, the remote sensing derived classification map and the ground truth reference test set;
b) K coefficient of overall thematic accuracy, that consists in a multivariate measure of agreement between rows and columns of error matrix.

After the reference data set was collected from randomly located sites, it was compared on a pixel-by-pixel basis with the present information in the classified satellite imagery. This source of information was also utilised to validate the results of the final procedure.

The processing executed in the second phase of this research was aimed at improving the MLH classification results (Figure 2), by testing conventional post-classification methods and proposing new solutions in order to remove spectral ambiguities and internal variability of thematic classes in error matrix.

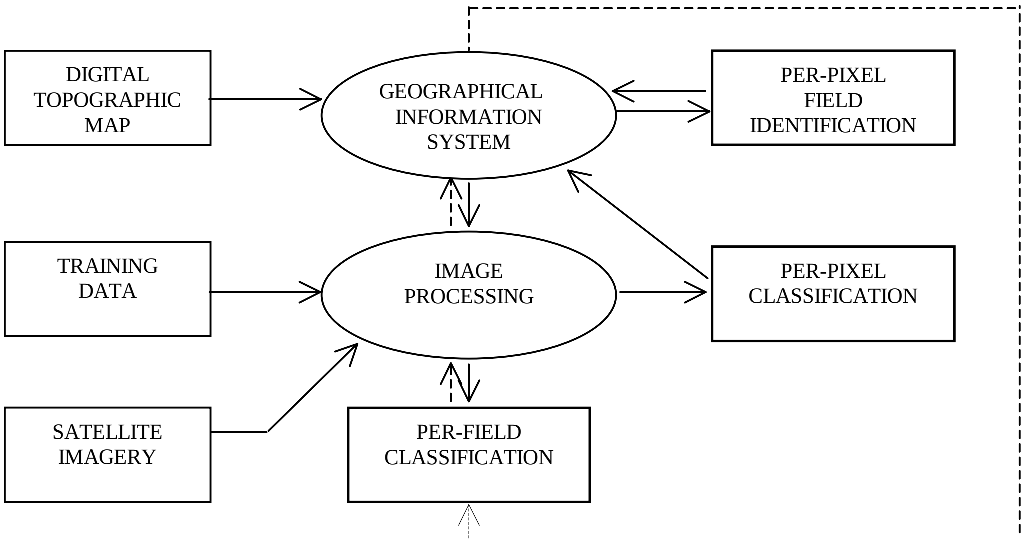

Figure 2 Analytical sequence of per-field classification procedure

At the beginning, a moving window algorithm at pre-determined step on the classified image was tested (Gurney and Townshend, 1983) and this was able to alter the central pixel class in function of frequency of classes assigned to surrounding pixels. This approach, majority filtering, is a simple post-classification procedure entailing the use of a 3x3 majority filter kernel.

Although, generally, noise level in the classified image was minimised, the input matrix dimension and the intrinsic decision rule of algorithm were inefficient for the identification of single regions, leaving classes attribution unchanged and removing information considered meaningful for recognition of the elements.

At this point, the classifier modification procedure was performed, in order to improve the accuracy and specificity of the elements, previously identified with MLH classifier in the image processing system (ERMAPPER), with the correction of misclassifications by providing spatial context (digital topographic map). In this case the spatial context is the geometry of a field that is an area in which only one land cover type is expected.

The integration of the IKONOS image and digital cartography in a scale 1: 5000 was achieved in a geographical information system (ARC/INFO). All relevant field boundaries was extracted from the digital cartography and processed as coverage in the GIS environment in order to perform the per-field classification. The polygon coverage was rasterized to a 4m pixel size, matching that of the IKONOS image, and the two raster data sets were combined in a single raster grid.

Finally, specific decision rules were realised (spatial dominance among heterogeneous classes in the same area), developed with *map algebra* spatial analysis language, in order to combine and to modify the original data structure for attributes of objects contained in external contextual information.

The accuracy of both post-classification methods (majority filter and per-field classification) were, next, compared with the initial MLH classification.

Table 1 Confusion Matrix of the Per-field classified IKONOS imagery of Fasano (Italy)

Reference data set					**Classified Land Use**				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	3843	0	49	0	7	27	53	16	55
2	0	159	4	12	3	1	94	350	92
3	0	37	22437	15	55	232	751	846	1538
4	0	0	0	5416	0	0	301	282	424
5	0	30	27	9	1553	631	221	124	27
6	580	0	148	0	114	5538	1088	518	478
7	3	9	10	239	7	4	1717	201	150
8	0	0	3	695	0	0	81	606	254
9	0	0	7	39	0	0	41	10	824
Overall Accuracy: 79.294% from 53085 observations									
Kappa coefficient: 0.721									

5 Results

The overall accuracy achieved by MLH classification (overall accuracy 68%) demonstrated correct execution of procedure, even if it underlined different problematic levels in recognising single land cover classes.

The majority filter application increased overall accuracy by 4% and, even if the level of noise in classified image was on the whole attenuated, it did not modify erroneous attribution of classes and moreover it removed information necessary for the identification of linear elements.

The per-field classification procedure effectively improved the final results (overall accuracy 79%), by reducing the internal variability of regions (Figure 3). In this way, this thematic elaboration constitutes a suitable input for a GIS database in specific application fields.

The disagreement of values emerged in the Confusion Matrix (Table 1), was ascribed to internal variability and erroneous identification of areas with the same spectral signature. Such disagreement was accentuated on cover edges and on linear elements, inside which mixed pixels due to spatial resolution of 4 m and isolated elements (trees, cars, etc.) were present with negatively interfering in result quality.

6 Conclusions

At present, an increasing amount of geographical data is stored in geographical information systems. This data could prove useful in the processing of remote sensing images. In addition, remote sensing images may be considerably applied to store and update data in a GIS.

Flexibility of the integration process in the software packages and the high spatial resolution of the new generation satellite imagery may globally lead to an increase in geometric detail and in accuracy, with which land cover can be mapped over images of coarser spatial resolution in which, as many recent researches attest, the presence of mixed pixel is the dominant problem to resolve.

The per-field classification approach proposed here had overcame spectral ambiguities and internal variability of land covers, by effectively defining elements in a more appropriate way and by resolving most misclassification problems of analysed areas. As the result of the whole procedure, inclusion of the topographic map information during the IKONOS image classification improved overall accuracy of the results (from 68% to 79%).

However, the effectiveness of methodology remained connected to the quality of accuracy obtained in initial MLH classification, that in this case had produced misclassifications, not only as a consequence of internal variability within fields, but also due to the utilisation of land use as opposed to land cover classes. Moreover, the definition of appropriate additional decision rules was also useful in overall process, in order to remove the effect of geometric distortions in registration phase of raster and vector data for certain steep sub-areas. Thus for some sections of the processed image it was possible to include heterogeneous classes in the same reference contextual entity.

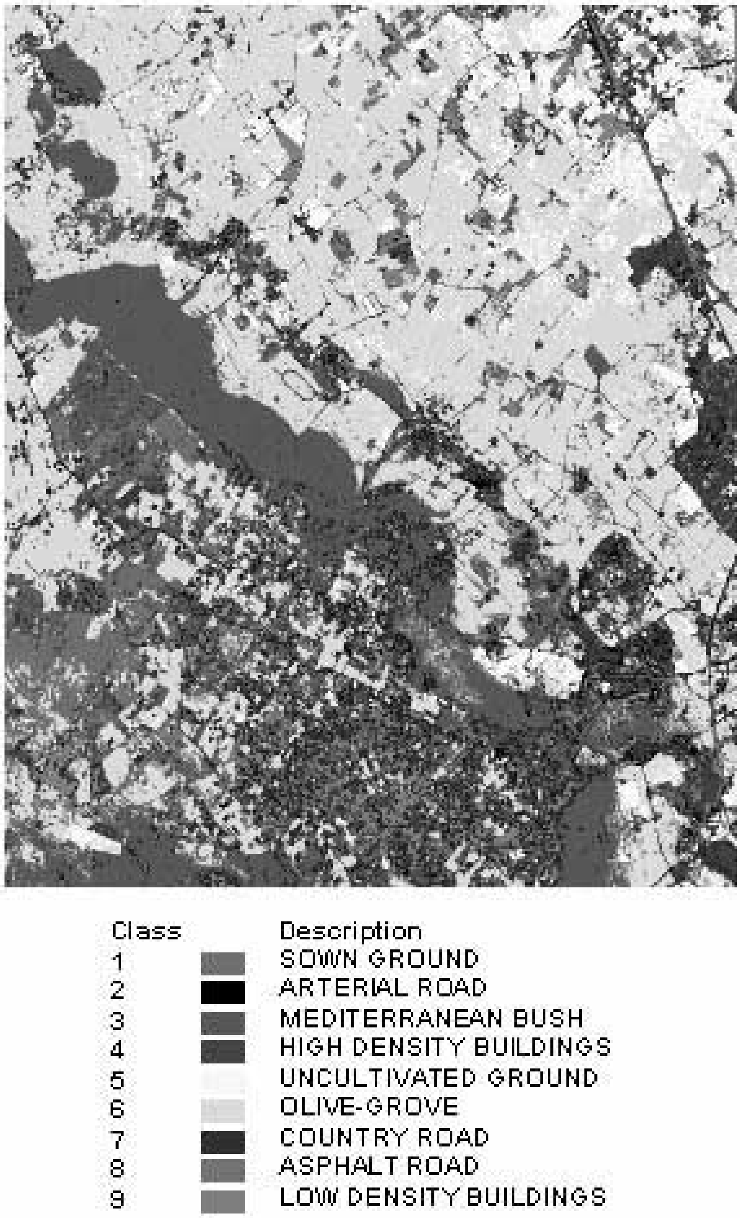

Figure 3 Per-field classified study area

The per-field classification developed in this paper should be considered as a test to validate on a local scale well established methodologies of classification applied at on over-regional scale and future researches are advisable to reduce sources of resulted misclassifications. Moreover, such types of studies allow opening of new unexplored techniques applicable on large scales by adding meaningful inputs to those multidisciplinary studies connected to decision-making and planning activities.

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