PER BLOCK URBAN LAND USE INTERPRETATION USING OPTICAL VHR DATA AND THE KNOWLEDGE-BASED SYSTEM INTERIMAGE

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ABSTRACT:

This study uses the InterIMAGE system and imagery from the QuickBird II optical sensor for the land use classification at two test-sites in the metropolis of São Paulo, Brazil. InterIMAGE is an open source and free access system for knowledge-based image classification. Within InterIMAGE human knowledge is represented as a semantic net and by user-defined rules that can emulate human reasoning based on the paradigms of the object-oriented image analysis. The two land use classifications were carried out considering the urban blocks of the test-sites as analysis units. After obtaining the land cover classifications of the two test-sites, customized features related to the composition, structure and geometrical properties of the land cover objects within these blocks were created. The description of the land use classes was done associating these customized features with membership functions and arranging these expressions in membership values aggregation structures. The proposed methodology has shown to be promising for automatic land use interpretation of complex urban areas such as that found in São Paulo. The land use classifications achieved Overall Accuracies above 70% in the two test-sites and Kappa Indexes of 0.69 and 0.53. This study has explored some of the main presently available potentialities of InterIMAGE for object-based and knowledge-based image classification. This application of InterIMAGE, as well as the system itself, is under development.

1. INTRODUCTION

According to the United Nations (UNO), presently more than half of the world population lives in urban areas and by 2050, this percentage will increase to 70% (UN-HABITAT, 2009). It foresees an absolute and a relative increase of urban population especially in developing countries. The chaotic growth of cities in developing countries causes different social problems, such as violence, traffic jams, visual and sound pollution, decrease of environmental quality, increase of diseases related to air pollution and depreciation of public spaces among others. The mitigation and solution of these problems involves effective urban planning policies based on up-to-date and reliable spatial information. The most important spatial information that urban planning is based is, along with population density, the land use.

In this context, remote sensing datasets can provide valuable information about the urban land cover. According to Jensen (2007), for urban land cover and land use classification at the third and forth scale levels of the United States Geological Survey, remote sensing multispectral imagery with a temporal resolution of at least three to five years and spatial resolution higher then 5 meters (< 5m) is required. In the last decade, several spaceborne sensors with these characteristics were launched. The growth in the availability of data demands now for adequate (i.e. accurate, standardized and fast) methodologies for information extraction. The object and knowledge-based image classification approach is presently the most advantageous for the analysis of high spatial resolution imagery with the finality of urban planning.

Despite the several potentialities of this approach, the costs of licenses for the use of commercial software that perform object-based and knowledge-based image classification are still very high. Another disadvantage is that these systems are not open source, which means that one cannot have access to the code of the algorithms nor customize the system according to one's own needs. The free access to these systems would allow planning agencies and research institutes, especially in developing countries, to make full use of this technology.

In that context, the objective of this work is to present an urban land use classification model using the InterIMAGE system (InterIMAGE 2010) and imagery from the QuickBird II optical sensor (DigitalGlobe 2008). InterIMAGE is a free of charge and open-source knowledge-based classification system whose image analysis conception is highly flexible, offering great potential for automatic interpretation of remotely sensed imagery (InterIMAGE 2010). The system is an on-going project whose main long term objectives are to spread its use among governmental planning agencies and research centres.

1.1 The InterIMAGE System

The InterIMAGE system is a knowledge-based framework for automatic image interpretation which is currently implemented for LINUX and Windows operating systems. The image analysis concept of InterIMAGE is based on an earlier system called GeoAIDA developed at the Leibniz University in Hannover (Bückner et al. 2001; Pahl 2003). The classification strategy implemented by InterIMAGE is based on a knowledge model structured as a semantic net defined by the user. The classification strategy has two steps: the Top-Down (TD) and the Bottom-Up (BU).

In the TD step, the system descends the semantic net triggering the so-called holistic operators. Holistic operators are image processing operators, external to the system's core, specialized in the detection of a certain class. Every node of the semantic net may or may not contain a holistic operator. These can be developed by any user who has programming skills. InterIMAGE (2010) also offers an online repository of operators developed already by the project team. In theory, the holistic operators can process any type of image, enabling InterIMAGE to perform multi-sensor analysis.

For the detection of objects from the corresponding class, holistic operators usually perform three procedures in the following order: (1) segmentation (or import GIS data), (2) attribute extraction and (3) classification. The geographic regions detected by a holistic operator inserted into a given node are transmitted as masks (hypothesis) to its child nodes on the lower level of the semantic net, where its own holistic operators will work. Presently, the user can customize a holistic operator considering: (1) one of three segmentation algorithms available in the system, (2) spectral, textural and geometric features and (3) classification rules using different aggregation operators structured, if necessary, hierarchically.

In the BU step, the system ascends the semantic network solving spatial conflicts between hypotheses based on user-defined rules inserted in every node that is not a leaf node. Doing so, the system either partially or totally discards the hypotheses or turns them into instances (i.e. validates the hypotheses). These user-defined rules may or may not involve additional logical selections. If after the discard of hypotheses by these additional logical selections spatial conflicts still remain, they are solved either by the supervised definition of priority for the classes or by the competition of membership values given by user-defined fuzzy membership functions. BU rules are customized in a friendly interface that allows the development of complex class description and hypothesis judgment criteria.

2. TEST-SITES AND METHODS

The test-sites for the application of the methodology are two sections of the São Paulo municipality, southeast of Brazil. One is a high social-economic standard residential area with two types of land use, namely: residential horizontal of high standard and vertical residential of high standard. The most common targets in that area are vegetation cover of trees and grass, houses with ceramic tile roofs, swimming pools and concrete residential buildings painted in white. The other test site is an industrial and residential area with bare soil areas, small houses with ceramic tile roofs, industrial warehouses with different kind of asbestos roofs, parking lots and bureau buildings. Both test-sites have a modest size of about 810.000 square meters. This limitation of image size is actually a limitation of the number of hypotheses (i.e. segments) that the InterIMAGE system could process by the time this work was carried out.

As explained below, the land use classifications were done taking the urban blocks of the test-sites as the elementary analysis units. For this reason, a vector dataset with the urban blocks of the municipality of São Paulo was accessed. For the description of the land use classes we utilized customized features related to the composition, structure and geometrical properties of the land cover objects (obtained in Kux et al. (2010)) located inside the urban blocks. This ontological approach for the land use classification was also successfully applied by Hofmann et al. (2008) and Kux et al. (2009) for the detection of informal settlements in Brazil.

The land use classes considered in this study were defined based on the official land use map of the city of São Paulo (PMSP, 2009). The following six land use classes were defined: Industrial Areas, Vertical Service, Service and Residential Mixed Use, Horizontal Residential of High Standard, Horizontal Residential of Low Standard and Vertical Residential of High Standard.

Several customized features were created such as *number of swimming pools*, *mean size of roofs*, *relative area of vegetation*, and *compactness of the biggest shadow object*. The customized features were created considering which features a human interpreter searches when visually interpreting the predominant land use of urban blocks. For instance, it is common knowledge that industrial areas have characteristically few large-sized clear and dark asbestos roofs. Due to this, the features *mean area of asbestos roofs* and *number of asbestos roofs* were created. When a photo-interpreter visually detects which type of land use predominates on a certain block, he or she considers in a complex way many evidences, features and assumptions at the same time. Some characteristics are more important than others but, depending on the situation, the level

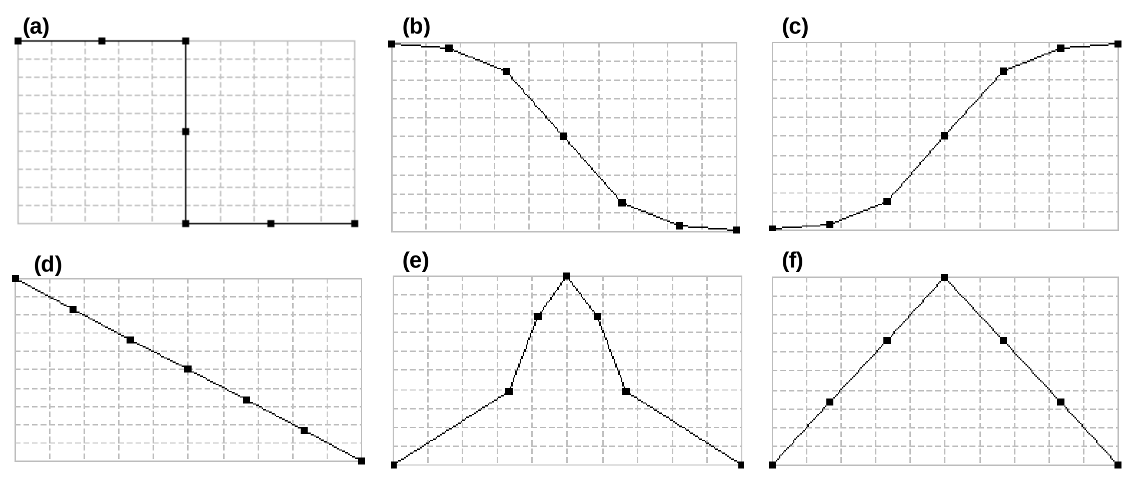

Figure 1 – Membership functions used for the descriptions of the land use classes. Lower and upper thresholds are always 0.0 and 1.0 respectively. Left and right thresholds are case dependent.

of importance of each characteristic may change. This complex knowledge that a human analyst has, can be represented using the right features, membership functions associated to these features and especially a hierarchical structure of aggregation of the membership values returned by the membership functions. The InterIMAGE system presently has the following five types of aggregation operators, which can be used on this structure of expressions: *minimum*, *maximum*, *mean*, *multiplication* and *sum*.

2.1 Land Use Class Description

The membership functions used in the description of the land use classes are shown in Figure 1. As blocks of land use class Vertical Residential of High Standard are characterized by the presence of large shadows with rectangular format as well as by the presence of many trees. Hence, the features *relative area of vegetation* and *maximum compactness of shadows bigger than 400* m^2 were used for the description of that class. For the first feature, the membership function *c* on Figure 1 was used with thresholds of 0.0 and 0.4. For the second feature, the membership function *c* with thresholds of 0.0 and 3.0 was used. The operator *minimum* was used for the aggregation of the membership values returned by these two membership functions. Likewise, blocks of Vertical Service land use are also expected to have large sized shadow objects, but differently from blocks belonging to class Vertical Residential of High Standard they generally have very low relative area of vegetation. For this reason, class Vertical Service is described with features *maximum compactness of shadow objects larger than 400* m^2 and *relative area of vegetation*. For the first feature, the membership function *c* on Figure 1 was used with thresholds of 0.0 and 0.4. For the second feature, the membership function *b* with thresholds of 0.0 and 5.0 was used. The operator *minimum* was also used for the aggregation of the membership values returned by these two membership functions.

Figure 2 shows the description of the class Horizontal Residential of High Standard. The squares represent the aggregation operators. After every feature used in the description it is indicated its membership function by a letter referring to Figure 1 as well as the right and left thresholds (Figure 2). The assumptions of this class description are that blocks with the predominant land use Horizontal Residential of High Standard usually have high relative area of vegetation (due to the big gardens in the houses) as well as low relative area of ceramic tile roofs. In blocks with such predominant land use it is expected that the number of ceramic tile roofs lies around seven to twenty. The land use class Horizontal Residential of Low Standard is described with features *relative area of vegetation* and *relative area of ceramic tile roof*. In blocks with such predominant use, one usually finds few vegetation and lots of small ceramic tile roofs inside of it. Hence, for the first feature the membership function *b* on Figure 1 was used with thresholds of 0.0 and 0.4. For the second feature, the membership function *c* with thresholds of 0.3 and 1.0 was used.

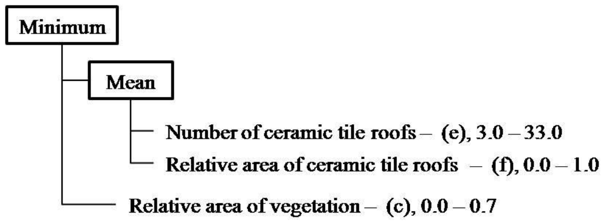

Figure 2 – Description of the land use class Horizontal Residential of High Standard.

Figure 3 shows the description of the land use class Industrial Areas. As presented in Figure 2, after every feature used in the description it is indicated its membership function by a letter referring to Figure 1 as well as the right and left thresholds. The assumptions of this class description are that blocks with the predominant land use Industrial Areas usually have very little vegetation and ceramic tile roofs as well as at least one large sized asbestos or blue-coloured roofs. These roofs generally have the rectangular shape. Hence, the bigger its compactness the more likely the block where it is located is of industrial use. At the same time, it is expected that industrial blocks lack large shadow objects. In the case where such are found, in order to avoid confusion with class Vertical Service, they must have low compactness values for the block to have membership to class Industrial Areas.

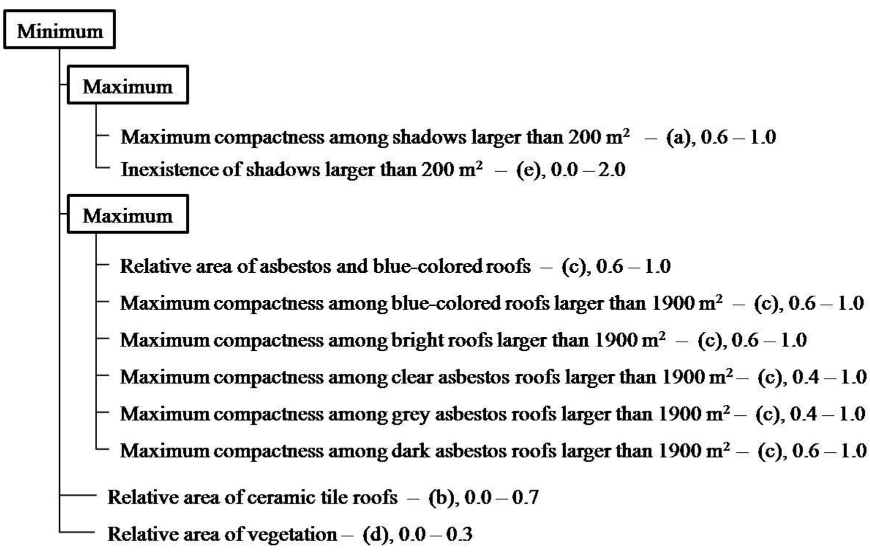

Figure 3 – Description of the land use class Industrial Areas.

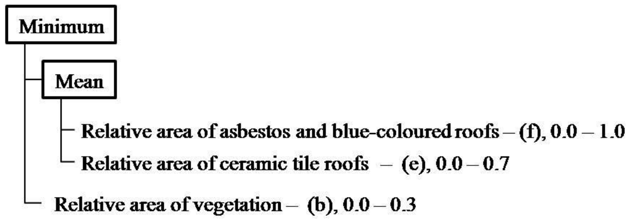

Figure 4 – Description of the land use class Service and Residential Mixed Use.

Figure 4 shows the description of class Service and Residential Mixed Use. The rationale behind this description is that blocks of that class usually have very few vegetation and about half of its area covered with asbestos or blue-coloured roofs and also about half its area covered with ceramic tile roofs. At the official land use map of São Paulo, these blocks are defined as land use uncertain.

2.2 Formatting of the Land Use Classification Model

In order to apply the proposed land use classification model, three new functionalities had to be implemented in the InterIMAGE system, namely: (1) the operator for the importation of results from other classifications done with InterIMAGE (Import_MAP-INET), (2) the *merge neighbours* function and (3) the capacity of the system to calculate features related to grandchild nodes. This last functionality is necessary whenever features like *mean compactness of roofs* and *maximum area of a roof type* are considered in a BU decision rule. The function *merge neighbours* is used strictly on BU decision rules when we want to merge adjacent segments of the same class and then calculate geometry features concerning the larger formed segment, which in theory is more representative of the real world object. As for the operator for the importation of results from other classifications, it permits that two classification projects of the same area (or with an intersection area) have results related to each other. That is the case in this study, where the results (i.e. validated hypothesis) obtained from the land cover classification were imported into the

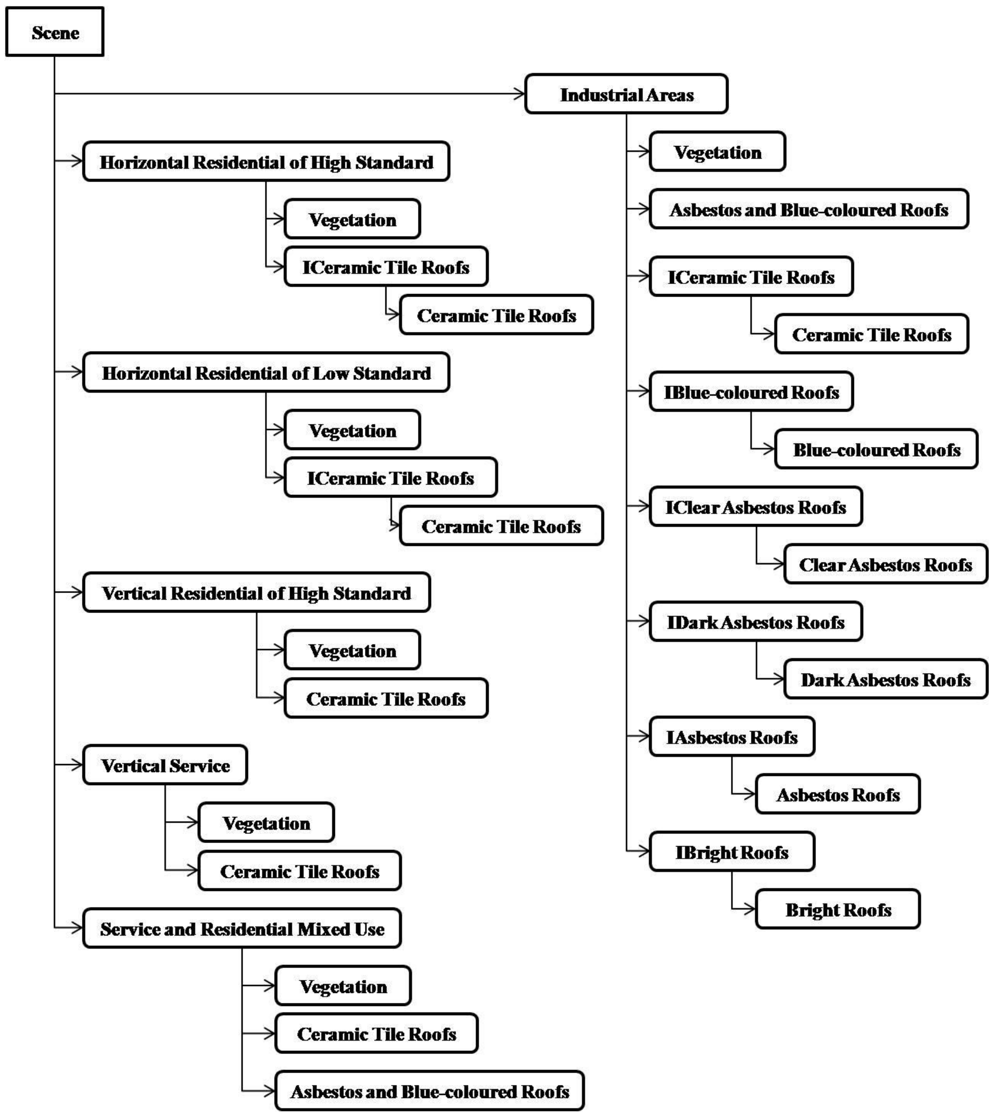

Figure 5 – Semantic net elaborated for the land use classification.

semantic net elaborated for the classification of the land use. Figure 5 shows the semantic net for land use classification.

In the TD step, the node Scene performs the importation of the vectors of the urban blocks from the area in *shapefile* format. This is done using the Shapefile_Import operator. To all the other nodes, except the leaf nodes of the semantic net, the Dummy_TopDown operator was inserted. As mentioned, this operator only passes down to its child nodes the masks it received from its parent node. The leaf nodes of the net perform the importation of the instances of the corresponding land cover class. For instance, the nodes named Vegetation import the instances of the classes Trees and Grass obtained in Kux et al. (2010). Likewise, the node Asbestos Roofs imports the instances of the land cover classes Clear Asbestos Tile Roofs or Concrete, Gray Asbestos Tile Roofs or Asphalt and Dark Asbestos Tile Roofs or New Asphalt. The importation of the instances of the land cover classes is carried out using the Import_MAP-INET operator.

In the BU step, the nodes whose names begins with the prefix 'I' (e.g. ICeramic Tile Roofs, IShadow and IAsbestos Roofs) only merge adjacent segments of the respective classes (e.g. in this case Ceramic Tile Roofs, Shadow and Asbestos Roofs) using the *merge neighbours* command. This is the only purpose for the existence of these nodes. Afterwards, the nodes of the land use classes (on the second level of the semantic net) validate the hypotheses of its child nodes and calculate the features used in its description (section above) and pass the values up the net. Finally, the node Scene accesses these values and calculates, for every urban block, the membership to every one of the six land use classes using the rules demonstrated on the section above. The class with the highest membership value is the one assigned to the urban block and the classification process is concluded.

3. RESULTS AND DISCUSSIONS

For the evaluation of the land use classifications, a reference map was produced through visual interpretation for each of the two test-sites. Some blocks located on the borders of the test-sites were not manually classified because its predominant land use is uncertain. The land use classifications were not evaluated based on the official land use map of the city of São Paulo because such a map is not available for the year of acquisition of the QuickBird image used in this study.

Figure 6 shows the land use classifications on the two test-sites and its respective reference maps. To ease the discussion, from now on we will refer to test-site labelled as *a* and *b* on Figure 6 as TS 1 and test-site labelled as *c* and *d* as TS 2. Based on a visual analysis of Figure 6 one concludes that there is high correlation between the reference maps produced by visual interpretation and the automatic classifications. As for the quantitative analysis, Table 1 shows the User's and Producer's Accuracies for all land use classes as well as the Global Accuracy and the Kappa Index (Congalton and Green, 1999) of both classifications. With the exceptions to be discussed, all classes achieved very good User's and Producer's Accuracies. The Kappa indexes calculated for the land use classifications in test-sites TS 1 and TS 2 are of 0.66 and 0.53 respectively and the Overall Accuracies are of 73% for test-site TS 1 and 74% for test-site TS 2.

In test-site TS 1 the class Industrial Areas was very well classified. Only one omission error and no commission error can be found in Figure 12. Class Vertical Service was also very well classified in TS 1 presenting only two commission errors and one omission error. This omission error refers to a block that has the features that describe class Vertical Service but it also has some vegetation. That made that block being wrongly classified as Vertical Residential of High Standard. As for the other classes in TS 1, the commission and omission errors were committed among each other. That was not unexpected due to the fact that the description of these classes are relatively similar and the blocks in that area are mostly square and small-sized which difficult the correct classification.

Most of the blocks in that test-area TS 2 were correctly classified. Exceptions are two blocks wrongly classified as Vertical Service when in fact their predominant land use is Vertical Residential of High Standard. The cause for these misclassifications is that these blocks have low relative area of vegetation, which has augmented its pertinence to class Vertical Service. In test-site TS 2 classes Vertical Residential of High Standards and Horizontal Residential of High Standards were, in

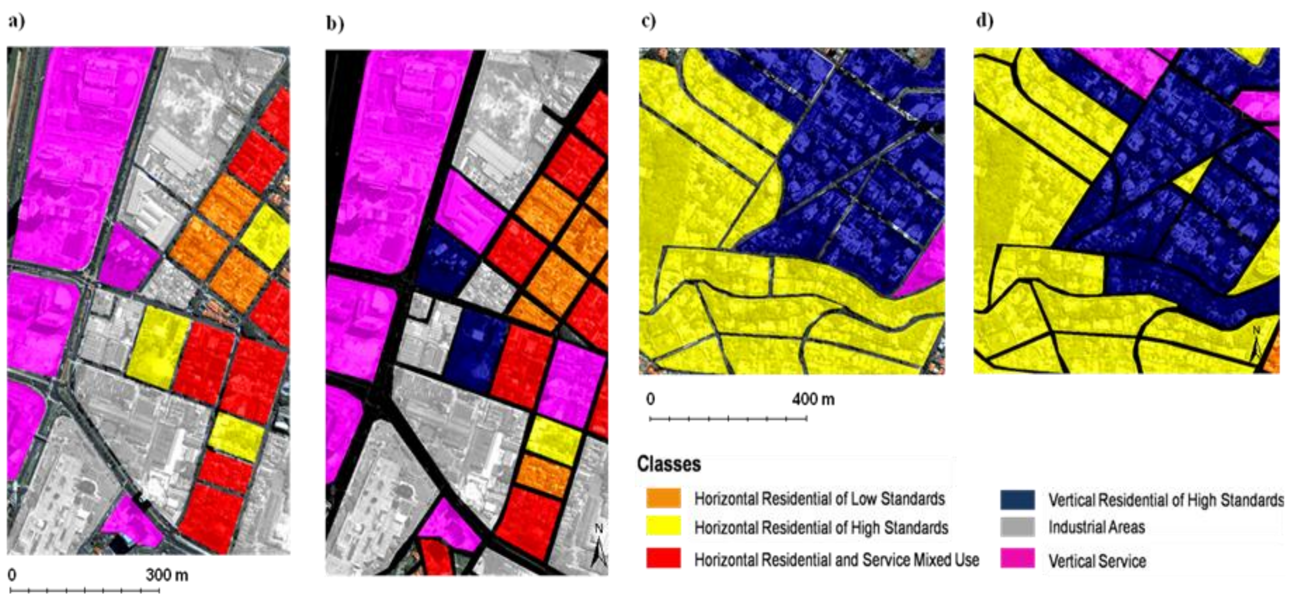

Figure 6 – Reference land use maps (a and c) and the automatic interpretation obtained with InterIMAGE (b and d).

	TS 1		TS 2	
Classes	**Producer's accuracy**	**User's accuracy**	**Producer's accuracy**	**User's accuracy**
Industrial Areas	0.88	1.00	--	--
Horizontal Residential of Low Standard	0.67	0.50	--	--
Horizontal Residential of High Standard	0.33	1.00	0.83	0.83
Vertical Service	0.80	0.67	--	--
Service and Residential Mixed Use	0.71	0.83	0.00	0.00
Vertical Residential of High Standard	--	--	0.70	0.78
Overall Accuracy	0.73		0.74	
Kappa Index	0.66		0.53	

Table 1 – Accuracy indexes for the land use classification at the two test-sites.

a general analysis, very well classified. Only one block of predominant land use Horizontal Residential of High Standards was incorrectly classified as Vertical Residential of High Standards and vice-versa.

Two final remarks should be made. First, as the number of blocks in the two test-sites is small, any misclassification is sufficient to significantly lower the accuracy indexes. That leaves to the qualitative analysis (i.e. visual comparison between the manually made and the automatic interpretation) to evaluate the classifications. Second, the thresholds of every feature and the membership functions associated with every feature could be further edited with the purpose of avoiding the misclassifications observed and hence obtain higher values for the accuracy index. This was not done because the land use interpretation model showed in this work was actually elaborate to perform interpretation over a much larger area and over any given date. The thresholds and membership functions were edited in a way that the corresponding classification is satisfactory over all of this larger area. The results of the application of this model over the large area and using the OBIA system Definiens Developer (Definiens, 2007) can be found in Novack (2009).

4. CONCLUSIONS AND REMARKS

This study has helped to demonstrate that the InterIMAGE system is a powerful tool for knowledge-based analysis of high resolution remote sensing imagery. InterIMAGE performed complex land use classifications using ontological features and user-defined rules. The functionalities implemented in InterIMAGE in order to make this application possible have certainly improved the system. The main limitation of the system is the still modest number of segments it can process, which has lowered the size of the test-sites. Nevertheless, the participants at the InterIMAGE Project are already working on this restriction. The experimental results presented in this study have confirmed that the InterIMAGE system will soon be an accessible tool for knowledge-based image analysis capable of being utilized as part of operational methodologies for land use mapping.

In future work, topological features recently implemented on InterIMAGE will be explored and the model will be tested in more extensive areas for the evaluation of its accuracy stability.

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