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DIFFERENTIATION BETWEEN FORMS OF URBAN DEVELOPMENT USING THE OBJECT-ORIENTED CLASSIFICATION METHOD WITH CENTRAL WARSAW AS THE EXAMPLE

Abstract: The aim of the paper is to present automated methods of discrimination of urban development forms using object-oriented classification in high-resolution images taken by the *Ikonos* satellite. The object-oriented classification makes possible to describe individual classes using not only the spectral reflection values but also the shapes, textures and topology of objects. The classification process as such is based on the theory of fuzzy sets.

The research covered an area of 25 km^2, situated in central Warsaw. As a result of object-oriented classification, five classes of development typical of large cities were distinguished and described.

Key words: object-oriented classification, land cover, land use, urbanized areas, *Ikonos*, Warsaw, eCognition, segmentation, classification.

INTRODUCTION

As a rich mosaic of land cover and land use forms, cities represent a complicated and difficult area for research. Urban areas are subject to dynamic change processes; where boroughs can expand in space, alter their appearance and functions.

Monitoring the development of cities and being aware of the status quo is necessary for taking town-planning decisions that ensure a harmonious development of the urban organism (Zalewski, 1997). Land cover and land use maps are important tools used in all kinds of urban planning work. Obtaining updated materials containing information about land use is both possible and cost-effective if we use remote sensing data.

Classification of urban development in satellite images is difficult because the structure and texture of land cover in urban areas does not allow automatic discrimination between different types of land use. In many cases, there is no distinct boundary between specific types of development, and hence decisions on the location of the actual boundaries are frequently made quite arbitrarily. Until recently, a detailed differentiation between types of urban development was possible only by visual interpretation. Traditional classification algorithms based on the spectral characteristics of individual pixels did not allow the discerning of individual types of development. The object-oriented method of classification, as discussed in this paper, has made it possible to overcome these difficulties in the identification of different development classes.

The study was conducted in a research plot with an area of 25 km^2, covering a part of central Warsaw (fragments of Śródmieście and Mokotów boroughs). The selected area was represented in an Ikonos satellite image with a spatial resolution of 4 metres for four multispectral channels and 1 metre for a panchromatic channel. The image was taken on 29 April 2000. The research area was characterised by varied land cover as well as different forms of land use. In this paper, five types of development were identified: high-density development, dense development, prefabricated high-rise residential development, low-density residential development, and service, warehouse and industrial development.

RESEARCH METHOD

Unlike classical algorithms, which are based on the statistics of spectral space produced by individual pixels, the object-oriented method of classification applied in this study deals with the identification of entire objects, specifically groups of pixels fulfilling the predefined criterion of homogeneity. The classification process makes use of information about the shape and internal differentiation of segments. Additionally, knowledge of object typology allows the inclusion of knowledge about the interrelationships between the classified objects in the description of classes. All object analyses were carried out using the eCognition software (Benz, 2001).

SEGMENTATION

The process of classification is preceded by segmentation, where an image is divided into objects. The method of multidimensional segmentation used in this study takes advantage of the local contrast of the image pixels, and distinguishes relatively homogeneous surfaces that differ from their surroundings. In the segmentation process, pixels are combined into regions and, in subsequent iterations, small objects are merged into bigger ones. Pairs of combined segments are selected to ensure that their combination produces the smallest possible increase of internal differences within an object. This procedure is repeated until the moment when the objects approach the maximum heterogeneity value of the generated region (Benz, 2001).

Identification of optimum boundaries based on local changes in contrast resembles the mechanism the human eye uses to discern objects. As a rule, the segmentation results closely resemble the digitisation results performed by the interpreter.

The generated objects can correspond to different degrees of research accuracy, depending on the segmentation features predefined by the user. The classification process can make use of several segmentation layers differing in the size of objects in order to introduce vertical relations between objects in the classification (Lewiński, Zaremski, 2004).

FEATURES DESCRIBING OBJECTS

Every object is described using a number of features, which can be divided into two categories: those describing inherent physical properties (object features) or those describing relationships between the object and other, earlier classified segments (class-related features). The eCognition software also allows for constructing features that are combinations of earlier defined object characteristics.

CLASS STRUCTURE AND CLASSIFICATION

Every class is described using at least one feature. For specific value ranges of individual features, the values of the membership function are defined. The application of the membership function allows translation of the classification into the language of fuzzy logic. The values of the membership function belong to the [0:1] range and show how much a given feature locates an object to a given class. A value of 0 means 'does not locate', whereas 1 means 'locates fully'. The remaining values from this range express the degree of membership to a given class.

Classes generated in this way are arranged into a structure called the class hierarchy. This hierarchy can be used not only to graphically arrange the existing descriptions but also to combine the classes into a network of mutual relationships. The applied mechanisms of interrelationships between the classes are mutually complementary. As a result, it is possible to obtain a better result than in the case of classification without combining the classes.

The prepared definitions arranged into a class hierarchy are comparable with the characteristics of objects identified in the image. The objects are ascribed to the class that are the closest in terms of features.

DISTINGUISHED CLASSES

DEFINITION OF CLASSES

The definitions of the distinguished classes used are provided below. The names of individual classes derive from the procedure (technology) used in the process of object classification, and therefore in many cases differ from the names used in the classical, visual interpretation of satellite images.

Fig. 1. Types of urban development: a. – high-density development; b. dense development; c. prefabricated high-rise residential development; d. low-density development; e. and f. service, warehouse and industrial development

I – **High-density development** (Fig. 1a)

Areas with high-density building complexes and those with artificial surfaces, concentrated along streets with small courtyards and small patches of greenery. Buildings stand close to one another and usually serve a number of functions: residential, service or administrative. High-rise (including tall buildings) and medium-rise development prevails. More than two thirds of the area of the blocks is filled in with buildings; sometimes the area is nearly 100% developed. This class mainly covers the central parts of large cities (Poławski, 2002).

II – **Dense development** (Fig. 1b.)

Areas with dense building complexes and those with artificial surfaces such as roads, squares, pavements and courtyards with small patches of greenery. Buildings stand close to one another; the residential function is the strongest, while service and administrative functions are not as significant. Medium-rise buildings prevail, with development reaching 50% of the area of the blocks, reaching 75% in some areas (Poławski, 2002).

III – **Prefabricated high-rise residential development** (Fig. 1c.)

Areas with well-spaced development, with individual buildings of varying sizes, intersected by relatively narrow streets. Many parking lots and grassed areas, as well as undeveloped plots (Krówczyńska, 2004).

IV – **Low-density development** (Fig. 1d.)

Areas with residential buildings for single and more families, and their surroundings (gardens, access roads), usually built on small plots, sometimes semi-detached, and rarely taller than two floors. Such buildings usually have small gardens.

V – **Service, warehouse and industrial development** (Fig. 1e and Fig. 1f)

Areas situated at a distance from the central part of the city, characterised by a nearly nonexistent share of green areas, with a prevalence of artificial surfaces (asphalt, concrete, etc.). Such areas provide locations for shopping centres, production plants and warehouses. Spaces between buildings are occupied by yards, parking spaces and access roads. Such areas are likely to undergo considerable changes owing to the increasingly stronger market mechanisms in the pricing of land in Poland. The relative proximity of the city centre leads to replacing production by services and the appearance of office buildings.

EXPERT KNOWLEDGE USED IN THE CLASSIFICATION

This section explains how additional information was used to identify individual classes.

For the land cover in the land use classification, it was decided to use information from the land cover map that had been prepared during the first stage of the classification process. In the CORINE Land Cover[1] legend, the definitions of classes related to built-up areas included areas built of typically 'urban' materials, impervious to water, from which buildings and the transport network are constructed (such as concrete, asphalt, etc.). In the case of continuous urban fabric, all research polygons had to have at least 80% of their area made from such impervious materials, while in the case of discontinuous urban fabric, the share of 'urban' surfaces in the cover should range from 30 to 80% (Bossard, 2000). The classes of development identified in the study were defined using a similar procedure. For each class, the required share of 'man-made materials' areas in the total object area was determined. Information about the cover was derived from the layer forming the product of land cover classification. The thresholds assumed for the anthropogenic surfaces in the individual classes are different than those in CORINE because the legend used for the purposes of this study is not identical with the original version of the European programme. In addition, the 'urban' areas in the thematic layer were significantly underestimated. In many cases, spreading tree boughs covered the real surface of the land below, which meant that anthropogenic areas were identified as a land cover class representing green areas.

Another useful observation for the identification of development classes is that finding low-density development tends to be unlikely in the actual city centre, and that such a probability increases with distance, i.e. the probability is higher in districts lying further away from the centre. A similar approach was adopted when distinguishing areas of service, warehouse and industrial development; it was assumed that their probability increases with increasing distance from the city centre.

Knowledge about classes occurring in lower segmentation layers was also included in the classification. The size of objects from the first level allowed the description of individual shadows cast by buildings. At the other levels, these segments merged with the adjoining ones and their discrimination was not possible. The shadows were recognized as dark objects with an area not larger than a quarter of a hectare (excluding water reservoirs). They had very low mean spectral values in all channels. The presence of the shadow class in the lower segmentation layers and their surface area made it possible to draw conclusions about the nature of the development, because the larger the number of tall buildings casting shadows the larger the surface area of the shadows.

[1] CORINE (COoRdination of Information on the Environment) Land Cover is a European programme aimed at preparing a homogeneous, 1:100 000 land cover map for the European Union. It is based on the interpretation of satellite images, supported by analysis of aerial photographs, cartographic materials and in the field reconnaissance.

THE CLASSIFICATION PROCESS

The classification of land cover and land use was divided into two stages. The first action was the classification of the satellite image, describing only

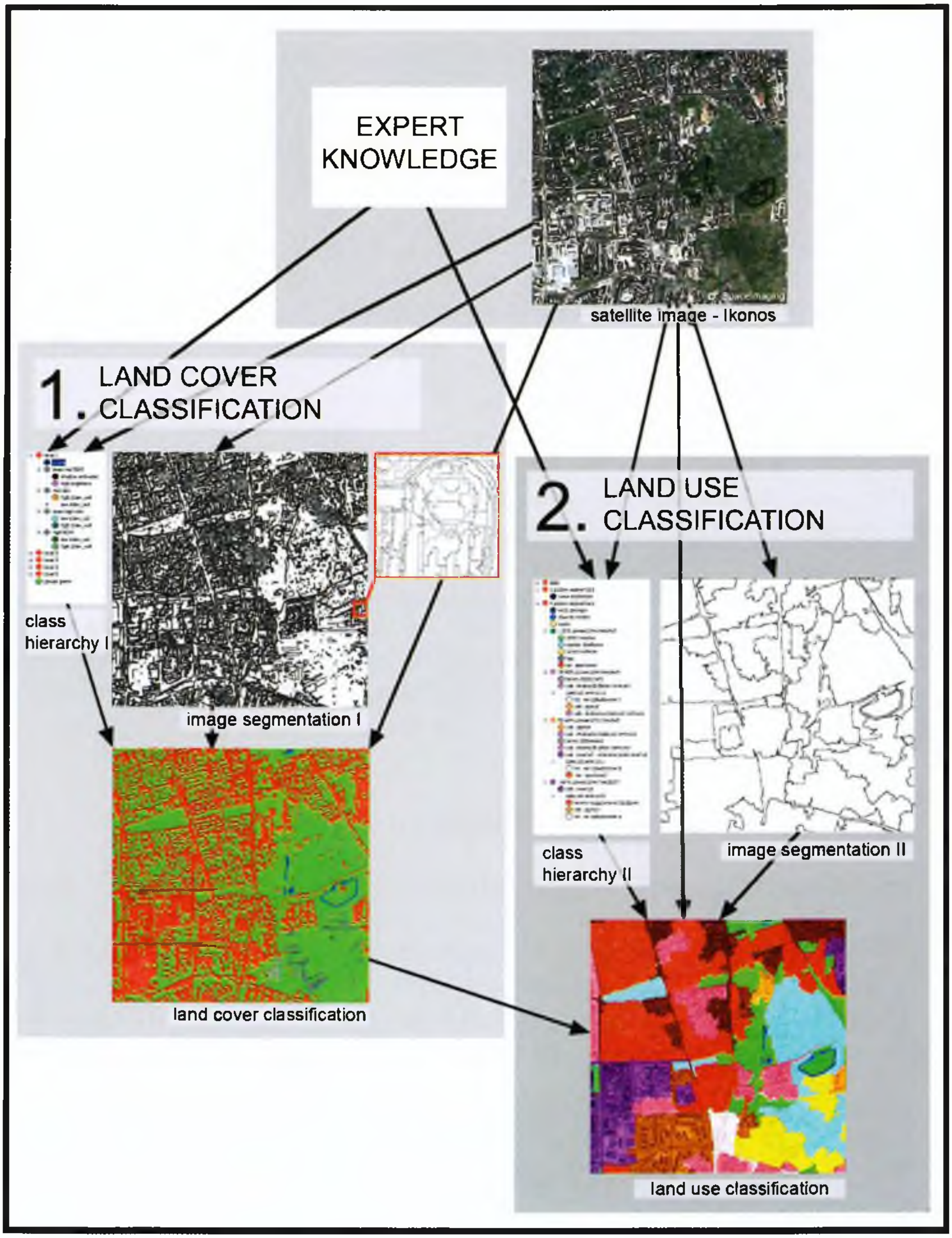

Fig. 2. Stages of the classification process

the land cover. It was used as a thematic layer from which information was derived for another, final classification, which also contained segments showing the type of land use. Figure 2 shows diagrammatically how the classification was performed.

STAGE ONE – CLASSIFICATION OF LAND COVER

A land cover map is a product of the classification process. In terms of accuracy, it corresponds to a scale between 1:10 000 and 1:25 000. The smallest distinguished objects have an area of 500 m^2. The following classes have been identified:

1) Anthropogenic areas – covered with asphalt, concrete, bituminous surfaces or other materials impervious to water and used to cover streets, pavements and roofs of buildings
2) Areas covered by trees, lawns or other green plants
3) Areas covered by bare soil
4) Areas covered by flowing water
5) Areas covered by standing water.

Following the segmentation process, over 191,000 objects were obtained, with an average size of approximately 131 m^2. In order to distinguish the intended classes, the values of the vegetation index NDVI[2] were used. It was assumed that the highest values would be recorded in areas covered by plants, and the lowest in areas covered by deep water, in this case water from the Vistula River. For the remaining values, average NDVI values were observed. For this reason, it was necessary to use other features available in the eCognition software to distinguish them.

STAGE TWO – CLASSIFICATION OF LAND USE

The segmentation of the Ikonos satellite image, conducted in several stages, was aimed at producing objects suitable to define city zones corresponding to the intended classes. As a result, four segmentation levels were generated and the last, highest level in the object hierarchy was subject to classification.

In most cases, the boundaries of objects generated in this way satisfactorily delimited the shapes and separated the intended land use zones.

[2] NDVI (Normalised Vegetation Index) was included in a set of features available in the eCognition software. It is a result of arithmetical operations performed on the spectral aspect of the Ikonos satellite image: red (VIS) – showing minimum reflections of green plants, and infrared (NIR) – showing maximum radiation reflections from healthy vegetation. It is calculated using the formula:

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

Altogether, 908 objects were obtained, with an average size of nearly 3 ha. These object boundaries were regarded as ones fulfilling the needs of the classification at hand. The most important boundaries between the distinguished classes of land use and land cover were captured. The existing inaccuracies and errors in running the line between individual segments were considered to be acceptable. The entire layer, which was generated semi-automatically, resembles the product of a manual digitisation of the image performed by an interpreter.

Following the segmentation of the satellite image, the process of defining the distinguished classes began. The characteristics of individual sections are described below, along with the values of the features[3] used to identify them.

I – High-density development

This class includes the majority of objects that in more than 66% were covered by 'urban' surfaces in the thematic layer. The probability is that this class will diminish with increasing distance from the city centre (from a point located central to the Palace of Culture and Science – PKiN), to reach a value close to 0 at a **distance** of over 5 km. In this class, objects with a smaller share of impervious areas were included as well, but they had to be **surrounded** by other segments categorised as *high-density development*. In some cases, objects with a high share of urban surfaces would be included in other classes, e.g. dense development or service, warehouse and industrial development.

II – Dense development

Segments belonging to this class were characterised by a high share of 'urban' surfaces, ranging between 50% and 66% (in some cases, objects in this range could be categorised in other classes, such as *low-density development*). In addition to that, beyond the actual city centre (a radius of over 4 km) objects belonging to this class with a share of 'urban' surfaces between 30% and 50% could also be discerned. These objects had **mean spectral layers values** for the blue panchromatic channel higher than 289 DN with the **standard deviation** of the panchromatic channel higher than 80, and higher than for the green panchromatic channel.

There were also areas classified as *dense development*, with a more than a 66% share of surfaces impervious to water. Situated at a distance of over 4 km from the centre, they were characterised by a **standard deviation** in the infrared channel of lower than 141 and a share of shadows at the first segmentation layer lower than 0.2 ha.

III – Prefabricated high-rise residential development

The probability is that this class will occur grows along with increasing distance from the centre. It has a 30% to 50% share of impervious surfaces from the thematic layer, with a **standard deviation** in the fourth channel higher than 163.4 and a relative border to brighter neighbours higher than 0.1%.

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[3] Names of features are bold-faced.

In this class, objects with a higher than 50% share of 'urban' substances were discerned less frequently. Their ratio in the panchromatic channel was higher than 0.198, and:

- **standard deviation** in the panchromatic channel was higher than 86.4

or

- **Standard deviation** in the panchromatic channel was lower than 86.4 and the **mean difference to brighter neighbours** remained within the range (12.32:15.48).

IV – Low-density development

Objects in this class have a 30% to 50% share in the surface of 'urban' materials from the layer containing information about the land cover. They are characterised by **brightness** values within the range (281:342), a **standard deviation** of the panchromatic channel lower than 80, and a fourth channel lower than 157. This class is rather unlikely to occur in the actual city centre area. However, in exceptional cases this class had **NDVI** values within the range (0.29:0.325), a **ratio** to the second channel lower than 0.195, and a standard deviation in the fourth channel within the range (132:148).

Low-density development was also identified among objects with the share of anthropogenic surfaces higher than 50% (and lower than 66%), which, further away from the centre, had the following values:

- **Ratio** to the first spectral channel lower than 0.1847

or

- **Maximum difference** higher than 0.4335
- **Standard deviation** in the panchromatic channel higher than 60 and the fourth panchromatic channel within the range (130:145).

Objects identified at a closer distance to the centre had a **brightness** lower than 286, with a share of shadows from the first segmentation level not higher than 0.35 ha.

V – Service, warehouse and industrial development

This class was characterised by a very high share of 'urban' surfaces (far in excess of 66%), high **brightness** (above 311), and a large **area** of objects (over 9.5 ha). The **shape index** values typical of this segment were under 3.5, accompanied by a relatively high **compactness**. The probability of the occurrence of this class in the city centre was equal to zero, and increased at a distance of approximately 2 km from the centre. In further districts of the city, areas with a high share of 'urban' surfaces which had at least a 300-metre common boundary with objects classified as *service, warehouse and industrial development*, were included in this category.

The results of the classification process are shown in Figure 3.

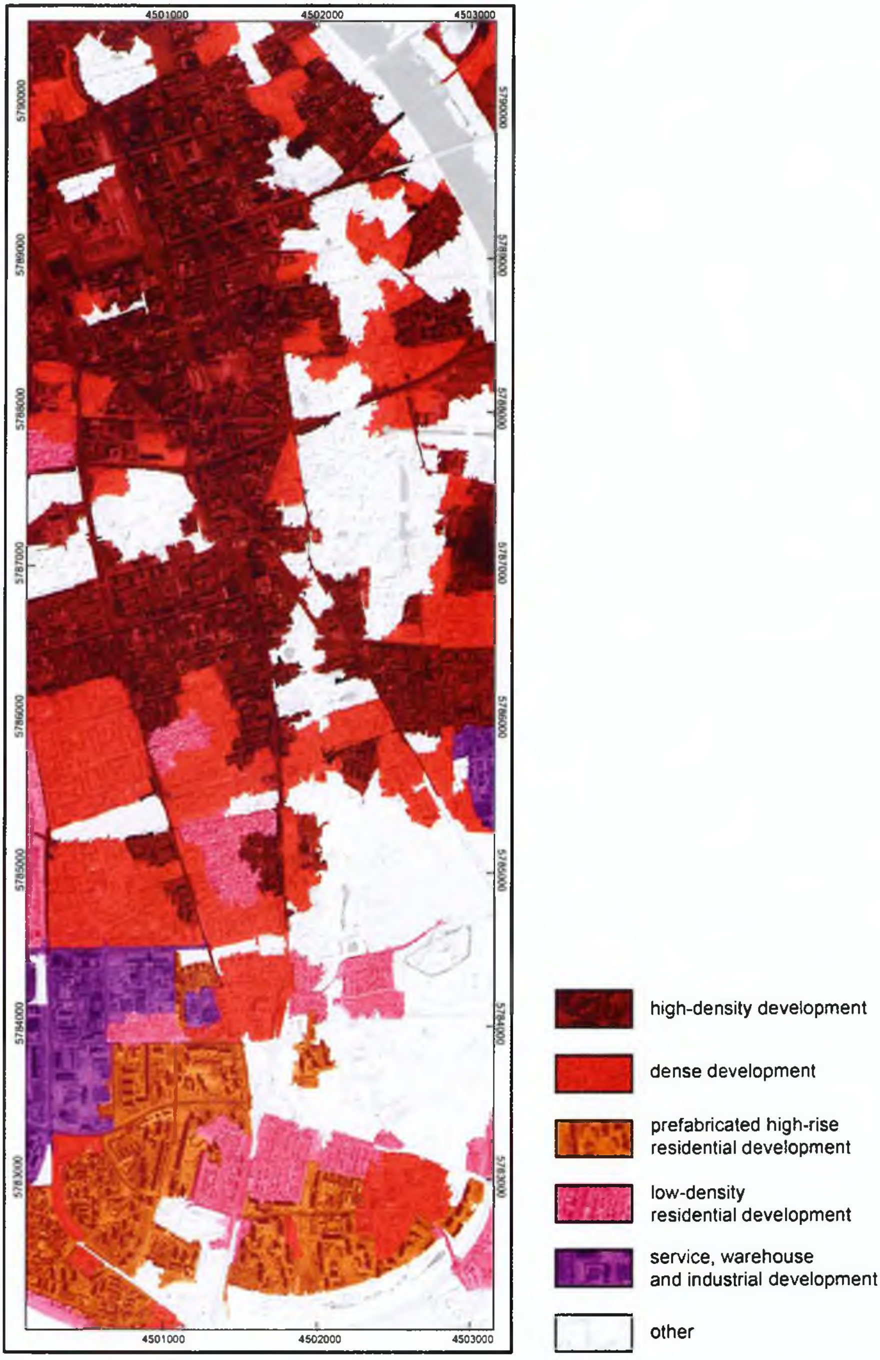

Fig. 3. Classification result – types of urban development

ASSESSMENT OF ACCURACY

The accuracy of the classification was assessed by comparing a set of reference points, these reference pixels randomly selected in the source image, with the results presented above. The result of the comparison is shown in the error matrix in Table 1. The total accuracy of the classification was 90%, and the Kappa coefficient was 88%.

Table 1.

Matrix error in the satellite image classification

		Classes discerned on the reference data						Omission error (%)	Commission error (%)
		1 – high-density development	2 – dense development	3 – prefab high-rise residential development	4 – low-density residential development	5 – service, warehouse and industrial develop.	6 – other		
Classes identified in classification	1	173	22	0	0	0	5	6	14
	2	11	87	0	0	0	2	26	13
	3	0	1	95	3	1	0	2	5
	4	0	5	1	82	0	12	5	18
	5	0	0	0	0	45	5	2	10
	6	0	2	1	1	0	196	11	2

This result can be regarded as very good, especially for a study using automated techniques. The best results were obtained for the class of *pre-fabricated high-rise residential development*, with a 5% commission error and a 2% omission error. Very good results were also noted for the class of *service, warehouse and industrial development*, with a 10% commission error and a 2% omission error. Interestingly, in the class of *dense development,* both the omission error and the commission error values were at a high level (26% and 13%, respectively), whereas the highest commission error was noted for the class of *low-density development* (18%).

An analysis of the distribution of values in the error matrix indicates that some classes were particularly susceptible to 'blending' – points belonging to one class were frequently classified as another class, and *vice versa.* This tendency was especially visible in the case of *high-density development* and *dense development.* The above classes have similar features, which can have a negative effect on the accuracy of the classification. As they are also semantically similar, it would be possible to improve the accuracy of the exercise by combining the 'blending' classes.

CONCLUSIONS

The classification of development discussed in the paper proves it is possible to recognize the image content automatically, even for detailed research studies like those into urban areas. In this case, the total accuracy of the classification reached 90%. The classification image obtained is similar in appearance to the result of the visual classification, which until recently was the only method applied to identify different types of development.

The use of this object-oriented classification method proved successful owing to the possibility to divide the image content into segments, corresponding both in shape and location to real objects, and to use fuzzy logic to incorporate knowledge about specific types of land cover and land use in the definitions of the classes. Importantly, the definitions of classes produced here can be used many times, to classify different kinds of satellite images generated by the same scanner.

The results of this type of object-oriented classification of urban areas described here provide an interesting arena for further research.

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