Classification of functional land use classes in several tens of urban areas in the Czech Republic from aerial photographs

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Abstract. The paper presents a remote sensing and GIS interaction for land use classification in urban areas. The first part of the project was to define classes for the urban land use. Cooperating urban planners preferred to process and evaluate only five land use classes; these were general classes which are called functional classes: residential area, production area, transport area, recreational area and other area. Each individual general functional class comprisesseveral more detailed land use classes used in city plans, a map documentation describing the present state of the city land use and the vision for its future several yearsperiod. To perform the classification, it was decided to apply the city plans as GIS data working as masks for city plan classes. The detailed city plans are mostly based on topographic maps of 1: 5 000 scale. There were two main tasks: to distinguish which parts of city plans are only plans and to find a classifiable classes or "subclasses" and if possible common for various urban areas even different cities. Aerial orthophotographs were used for the classification; the data present the real land use state with 50 cm resolution, however in a non-classified detailed raster layer. The project focused on defining urban development was processed on an example of 35 Czech cities. They differed by their sizes, number of citizens, and many other aspects like their altitude, terrain morphology, etc. The classification was split into several steps: selection of areas of the same city map classes and comparison of their thematic subclasses content for individual parts of cities and cities, and definition of the remaining classes and their subclasses. Final functional classes were derived by reclassification of the detailed lower level classes according to their definition of urban planners. The advantage of this approach can be found in the detailed analysis, which allowed us to classify urban areas with high thematic accuracy on one side and reliable thematic accuracy using the classification of urban planners. The paper will present which land use classes and their subclasses including their signatures were used for determination of the functional classes.

Keywords. Czech cities, land use class, urban areas, aerial photographs, laser scanning, classification

1. Introduction

The project "Modeling of urban areas to lower the negative influences of human activities project, processed at the Faculty of Civil Engineering deals with the analysis of highways and motorways and other roads on the urban development of Czech cities. This large project comprised an important and time consuming part – mapping of land use of 50 Czech cities from end 1960's till 2010. The maps covered 40-year-long period in approximately 10-years periods. The maps were processed using city maps and aerial photographs from Czech archives. The relation between road transport and urban development was based on development of road traffic intensity, which has been measured since 1968 in selected points in cities and on other roads, and urban land use classes and their development as they are defined by urban engineers.

This period (end of 1960 – 2010) is an important period due to political change in 1989. We have processed in fact last 20 years of the communist political and economical regime and first 20 years of the new state – democratic regime with changing ownership from the state and co-operative one (1960 – 1989) to the private one (1990 – 2010).

One of the project outputs is Atlas of urban development in Czech cities(since 60-ies of the 20th century)

2. Land use data and their determination in individual years

Definition of classes is one of the most important tasks in remote sensing classifications, in GIS layers and city maps as well. The goal of the project was to offer an analysis of urban development of various cities with various conditions and its impact to the road traffic and vice versa. City planners use a relatively wide range of classes, which are not unified at all cities. However, these classes were usedas a base for definition of five unified and generalized classes for all cities. Example of original city maps classes and their reclassification to more general and final 5 land use classes is in Table 1. This hierarchy approach is suitable for GIS analyses of final classes and data topology control and correction of topology errors.

Table 1. Example of reclassification of city map classes to functional classes

Area type in city plan	Aggregated type ofland use	Functionalclass
mixedresidental area	housing	residentialareas
generallyresidental area		
purelyresidental area		
ruralresidental area		
public spaces		
centralmixedterritory	amenities	
civicamenities		
areasofworkactivities	production and storepremises	productionareas
production area, industry		
sportssurface	recreation	recreation area
gardeningcolony		
parks and cemetaries	greenery	
gardens		
area close to nature		
othergreenery		
waterfeatures	water	
growingareas	agriculture	otherareas
vineyaerd		
agriculturalland		
railway	transport	transportationareas
road I. II. III. class		
localroads		

The functional classes were mapped from city plan classes (first column in Table 1) by GIS reclassification. The vector data had to be corrected from the topology point of view – removing slivers, holes, internal polygon boundaries, etc.

Functional classes in 2008 (2009, 2010) were determined by a visual control with using aerial photographs. This control enabled us to avoid urban planners' proposals. The year was given by the year of processing and available aerial photographs. It was the first map layer of each city of the latest time level.

The previous time instant was mapped applying the newer map – for 2000 year the map from 2010 was used. The map was processed as a corrected copy of 2010 map where all polygons were controlled using the aerial photographs from 2000. The same procedure was repeated for 1990, 1980 and 1970. Several cities were mapped from 1950 aerial photographs.

3. Land use data and remote sensing

The visual verification of individual functional classes of aerial photographs and other remote sensing data is a long time process, which is influenced by subjective perception of an operator. His experience and even his tiredness and attention at the moment of processing can have a serious impact on his result of the visual interpretation and manual classification.

Therefore using the aerial photographs, the process of the visual processing should be replaced by an automated classification as it is in most cases of the satellite data.The aerial photograph objects whose signatures can be defined in an easier way than the land use functional classes must be determined. They willform classes, which can be automatically classified.

Examples of the residential and recreation area classes are placed in Table 2.The examples show that several main remote sensing classes compose each functional class. The process from a functional class to classes, which can be used for the remote sensing classification, depends on several main aspects. The most important aspects are an experience of the operator and a tool the operator is able to use. Every city has a characteristic type of functional classes reflecting mainly a historical development of the city –historical city centres, residential areas with detached family houses, block of flats, etc.; another source of differences can be found in the economic power of cities. These are often surrounded by newly built "satellite cities". These are neighboring areas – built in prevailing part on previous agriculture land in the Czech Republic after 1990.

4. Classification process

4.1. Classification of laser scanning data

The classification of remote sensing classes was performed with application of two data sources. Aerial laser scanning data were the first and aerial photographs were the second data for the classification.

Laser scanning data has been collected since 2009 with 1,3 points per sq. m density. The original data forming digital surface model(DSM) were smoothed and the raster of slopes was calculated.

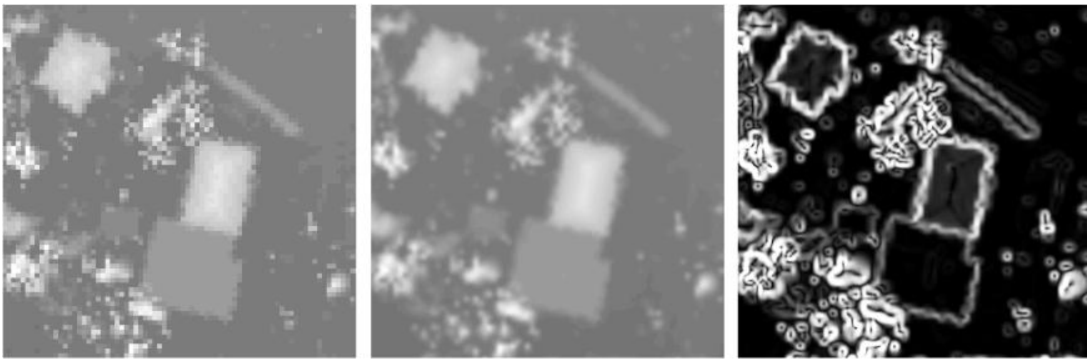
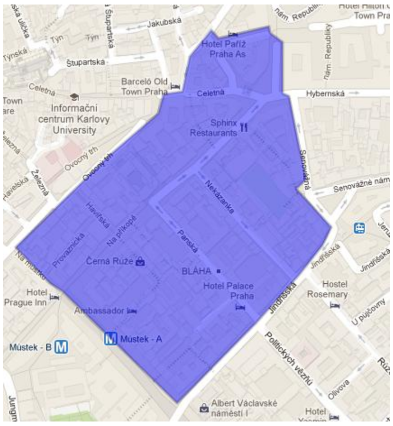
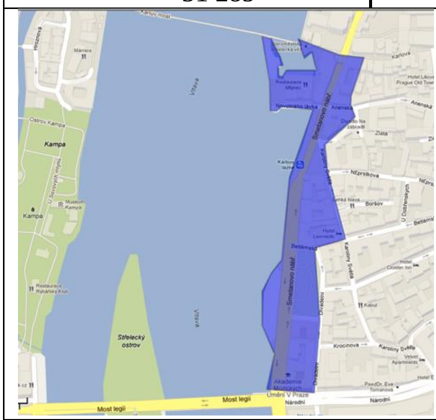


Figure 1. Laser scanning data – original (left), smoothed (middle), raster of slopes (right)

Table 2. Examples of functional land use polygons/classes

			
Residential polygon area (sq.m)	Buildings (sq.m)	Roads (sq.m)	Green area (sq.m)
144776	111157	28721	4898
			
Residential polygon area (sq.m)	Buildings (sq.m)	Roads (sq.m)	Green area (sq.m)
31 285	21 550	5 600	4 135
			
Residential polygon area	Buildings (sq.m)	Roads (sq.m)	green area (sq.m)

(sq.m)			
35471	15010	9851	6084

Recreational polygon area (sq.m)	Roads/path (sq.m)	Green area (sq.m)	Sport area (sq.m)	Other (sq.m)
604 015	39 179	529 545	5 079	20 352

The Figure 2 shows classification based on a similar slope and region growing method.

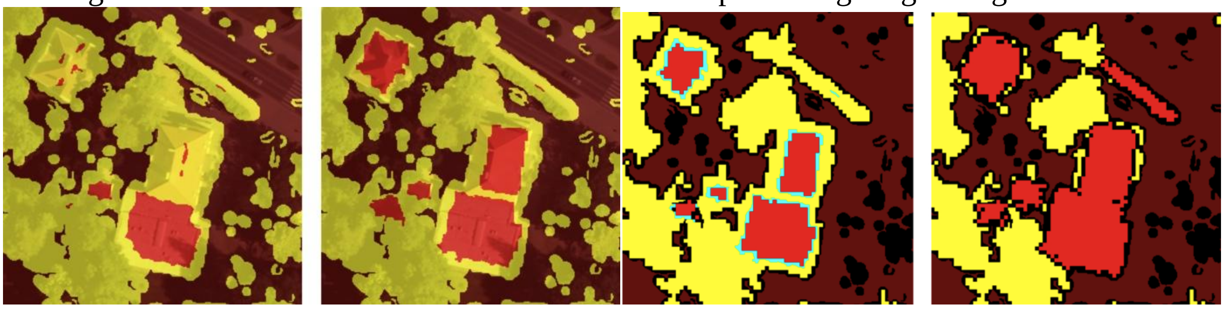


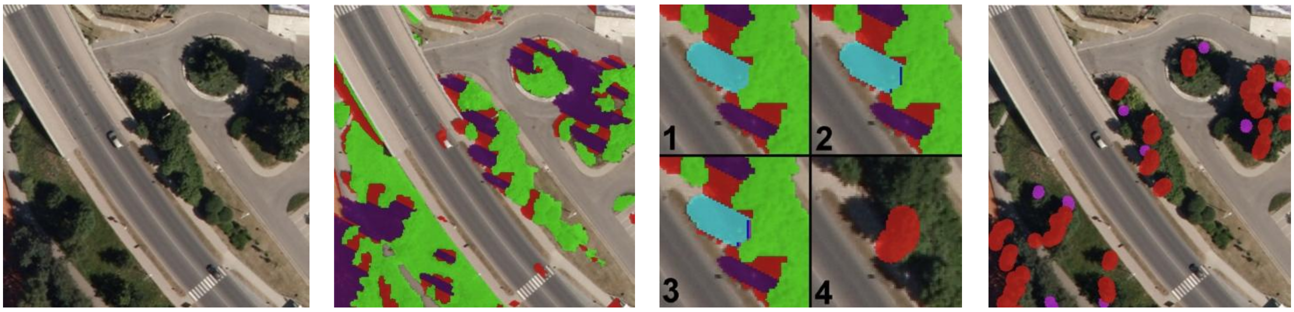
Figure 2. Example of classification of houses (= basic remote sensing classes = objects) having similar slopes of roofs and region growing algorithm

4.2. Classification of aerial photographs

A high detail of aerial photographs bringing easy understandable data must be suppressed by “an internal compression” of these details – various objects on roofs, their shape, different more or less shadowed roof parts, vehicles on rows, individual parts of tree crowns, etc. The easiest way is to classify the data by the object oriented classification. This classification allows us to work with whole objects and not to take into account their internal non-homogeneity.

Application of 3D data is another important input to classification, which has proved to be very important.

Classifications of aerial photographs were performed using eCognition software. The overall classification was composed from tens of individual steps. One example of classification principle is a classification of line vegetation alongside roads. This classification determined vegetation and separated trees and low vegetation. This diversification was based on trees shadow lengths. The example of the approach is presented on Figure 3.



a) b) c) d)

Figure 3. Example of classification of trees s) original aerial photographs, b) classification of vegetation and shadows, c) separation of individual shadows of individual trees and delineation of individual trees, d) classification of trees

4.3. Classification of urban land use

The final functional class areas are defined by their boundaries – polygons. These polygons are determined by urban architects. Even the most detailed functional classes (1st column in Table 1) are formed by several basic classifiable remote sensing classes/objects ashouses, roads, trees, vegetation, pervious surfaces, etc.Each polygon of a functional class is characterized by its attributes. These can be basic land use classes =basic objects, area sizes of individual basic objects = classes, whole area of individual basic classes,class diversity (number of various basic remote sensing classes), number of polygons of individual basic classes, e.g. This set of attributes is a signature space of individual functional class polygons.Table 2 shows examples of several functional classes.

It is the GIS approach,which evaluates all results of remote sensing classifications of basic classes and allows determining the signature space. The vector layer of basic objects' classification is overlaid by the vector layer of urban land use/functional classes. All necessary data are then easily derived and stored for all individual functional polygons.

5. Results

The accuracy of classification was calculated for individual classes – houses and trees alongside roads is in Table 3. The results of classification of houses from laser scanning data are comparable to the accuracy of classification of trees from aerial photographs – both in numbers and their area sizes.

Table 3. Example of classification results

	Classified	Referenced	Accuracy %
Laser scanning data			
Number of houses (size > 25 sq. m)	348	368	84,3
Area of houses	23 600 sq. m	26 108 sq. m	90,4
Aerial photographs			
Number of trees	519	604	85,9
Area of trees	21 234 sq. m	19 978 sq. m	94,5

6. Conclusions

Land use urban functional classes defined by urban architects cannot be classified directly from aerial photographs. All functional land use classes comprise several basic land use classes classifiable from remote sensing data (aerial photographs). The content of functional classes were verified using city maps and showed that the difference of signature space of individual functional classes is relatively high not only among various cities, but also among individual parts of one city (examples in Table 2). Therefore the classification of land use functional classes was not determined directly by automated classification. All functional areas were described by GIS data types derived from a detailed classification of basic land use classes – houses, streets, vegetation, etc. These data types are number of basic classes, areas of basic classes, total area of basic classes, and number of objects of individual basic classes, etc.

Remote sensing specialists define remote sensing basic classes and perform classification of these detailed land use classes.

The determination of content of generalized land use classes is then derived from detailed classes by GIS layover of the classification by map of polygons of functional areas.The content = description of these functional classes is stored as a list of attributes assigned to each polygon of functional classes

The future work will be focused on analysis of the best way to determine land use changes in functional land use classes.

Acknowledgment

The research was processed within the project OC 10011 of the Ministry of Education, Youth and Sports:Modeling of urban areas to lower negativeinfluencies of humanactivities.

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