MAPPING AND UPDATING MAPS IN DENSE URBAN REGIONS USING HIGH RESOLUTION DIGITAL AIRBORNE IMAGERY, SURFACE MODELS AND OBJECT-BASED CLASSIFICATION

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ABSTRACT:

Over the last couple of years more and more analogue airborne cameras were replaced by digital cameras. Digitally recorded image data show significant advantages to film based data. Digital aerial photographs exhibit a much better radiometric resolution. Image information can be acquired in shaded areas too. This information is essential for a stable and continuous classification, because no data or unclassified areas should be as small as possible. Considering this technological progress, one of the basic questions is how the potential of high radiometric and geometric resolution data can be used in an automatic analysis particularly in urban regions. For this study an object-based classification algorithm was selected to evaluate its suitability to update maps.

In this project, image data of two digital airborne cameras were used. The High Resolution Stereo Camera - Airborne eXtended, HRSC-AX, an extended version of the HRSC-A and the Vexcel UltraCam*D*. Both cameras provide similar good and accurate image data and Digital Surface Model (DSM) data, but they cannot be directly compared, as both have different spectral and spatial characteristics and different pre-processing.

Both resulting data sets were used in two separate analyses to develop and test an automated object-based classification procedure using the commercial software Definiens Developer. Taking the aim of map updating into account, emphasis was set on the delineation quality of buildings and correct detection of vegetation and impervious surfaces. As project area the centre of Berlin, Germany, was selected.

1. INTRODUCTION

The present development of urban areas is characterized by rapid changes. In the context of rapid expansion of many cities to enormous agglomerations with high population density and a world-wide urbanization process and due to the serious impacts on environment in urban areas there is a high demand on development and application of efficient technologies which allow to analyse and monitor changes in urban areas and support the planning decisions in these regions. The interpretation and analysis of multitemporal image data sets of high resolution and digital surface models ease land use and inventory mapping, assessing building progress and changes and new developments in parks and open spaces.

Due to the high heterogeneity and diversification of these regions not only the need of very high geometric and radiometric resolution remote sensing data increases, but also the need for reliable and automated analysis algorithms. To consider is that the increasing resolution of image data makes the analysis of the urban areas very complex (Oczipka, 2007).
Pixel-based classification algorithms are inappropriate for the classification of very high resolution image data (Blaschke, 2000a; Koch et al., 2003; Diermayer et al., 2006) as contiguous objects are often separated due to their spectral variability.

Previous studies showed (Oczipka, 2007; Hofmann et al., 2006; Taubenböck et al., 2006; Hofmann, 2001) that object based image analysis is suited to classify very high resolution image data due to its ability to merge pixels to meaningful objects. In this case study Definiens Developer 6.0 was used.

The goal of this investigation is the land use classification of a highly structured urban area with special consideration of building monitoring in order to update cadastrial maps.

2. STUDY AREA AND DATA SOURCES

2.1 Study area

As project area the centre of Berlin, Germany, was selected. Two different data sets with different radiometric and geometric resolutions were used. Because of the German history, separation and re-union, Berlin is a subject of quick changes. Especially in the centre, old buildings were removed and bare land was built up. The centre of Berlin is characterised by high spectral and geometric heterogeneity. Typical for this area are variable types of land use, like built-up areas from various time periods in different densities, covered with various roof materials as well as water bodies, diverse vegetation, sport fields, swimming pools and miscellaneous asphalt or concrete surfaces. The study area covers about 1,8 km², equivalent to 10200 x 7800 pixel in HRSC-AX and 21800 x 16700 pixel in the UltraCam*D* data.

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2.2 Data sources

HRSC-AX
The image data of two different sensors were used. The High Resolution Stereo Camera - Airborne eXtended, HRSC-AX, an extended version of the HRSC-A and the Vexcel UltraCamD. (Litaturnachweis)

The construction of the HRSC follows the concept of a pushbroom scanner. Within the photogrammetric processing five panchromatic bands are used to create true orthophotos and a digital surface model (DSM) using a hierarchical least square matching algorithm. Based on this DSM orthoimages for all four multispectral channels (blue, green, red, infrared) and the high resolution panchromatic nadir channel are calculated.

Typically the geometric resolution is 20 centimetres in X, Y and a decimetre in Z, in the nadir channel the resolution is increased by a factor of 2.

The radiometric resolution of the HRSC-AX is 12-bit for each channel. For most applications an IHS-transformation using the nadir channel is performed. The resolution is reduced to 8-bit to reduce the amount of data.

In this study the original 12-bit data were used to maintain the full information content especially in shaded areas.

Due to the different viewing geometries of the multispectral channels problems in the ortho-rectification occur where the DSM is not absolutely correct. This causes problems in the coregistration of the multispectral image data mainly along sharp edges in the DSM (buildings), which influences the quality of the segmentation. Another effect of the viewing geometry is the asynchronous recording of moving objects, which therefore appear at different positions in the multispectral channels, which may cause additional problems in the classification.

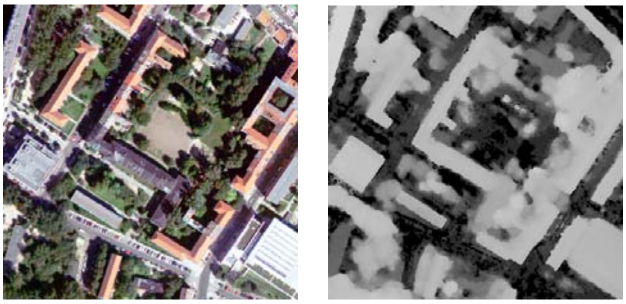

Figure 1. Detail of HRSC-AX data set: multispectral and a nDSM

UltraCamD (UC)
The Vexcel UltraCam*D* is a frame camera with four multispectral bands (three band true color [RGB], near infrared [NIR]) and a panchromatic band. An automatically generated DSM was derived using the semi global matching (SGM) process (Hirschmüller, 2005). For the UC not only a pan sharpening (IHS transformation) but also a 12 to 8-bit conversion was executed. These processes help to normalize the data sets and support the generation of continuous and regular image mosaics. Image mosaics are the data basis for the classification. The geometric resolution of this data set is about seven centimetres in X, Y and Z.

Due to the different matching algorithms the DSM of the UC data shows different characteristics as the HRSC-DSM, sharper edges are observed. On the other hand other problems occur along the outlines of high vegetation, which is caused by the different orthoimage generation process.

Both multispectral data and DSM were used in the segmentation and classification process. DSM represent not only the object heights, they also include the terrain height. In flat area this does not cause major problems. As the classification method should be transferable also to targets with high relief, the DSM has to be normalised to the ground height (nDSM). This was done for both data sets using a laser DTM.

Figure 2. Detail from UltrCamD data set: multispectral and a nDSM

3. METHODOLOGY

Both resulting data sets were used in two separate analyses to develop and test an automated object-based classification procedure using the commercial software Definiens Developer. Object-based classification algorithms are a good alternative for the classification in urban areas due to their ability to segment the image data. The crucial advantage of the object-based classification approach compared to a pixel-based approach is the possibility to also use geometric characteristics, textures and neighbourhood relationships of objects in addition to spectral features for class description. These features are essential to separate classes and create a reliable classification. Using the tiling and stitching tool, rule sets are easier to develop, because a smaller data speeds up to trial and error. Rule sets could then easily be transferred from one to another image data set. The results are merged in continuous mosaics using the server technology and the stitching tool. Although two different rule sets had to be created due to the different features of the data sets, the structure and the resulting classes are similar.

Both classifications were evaluated by qualitative and quantitative accuracy assessments. In a last step, an intersection of classified buildings and buildings in the ALK (see 0) was executed.

3.1 Segmentation

The pixel clusters generated in the segmentation step are the basis for the subsequent classification. The resulting segments should represent meaningful semantic objects of the real world structures (Baatz & Schäpe, 2000). In this way the object-based classification approach comes closer to the real world characteristics than the pixel-based. The meaningful segments are crucial for the subsequent classification (Blaschke, 2000b). Taking the size and shape of objects and their heterogeneity into account the object segmentation in both data sets was executed in several different scale levels using the multiresolution segmentation approach.

level	Purpose	Scale Parameter	Homogeneity criteria	
			Color / Shape	Compactness / Smoothness
7	buildings, overhead railway	Copied from level 6		
6	Objects in motion	100	0.8 / 0.2	0.5 / 0.5
5	Roofs	100	0.8 / 0.2	0.5 / 0.5
4	Elevated objects	90	0.6 / 0.4	0.8 / 0.2
2, 3	Water bodies, Vegetation, Asphalt, sport fields, Sand etc.	40	0.9 / 0.1	0.7 / 0.3
1	shadow	20	0.9 / 0.1	0.6 / 0.4

Table 1. Segmentation parameters for HRSC-AX data set

level	Purpose	Scale Parameter	Homogeneity criteria	
			Color / Shape	Compactness / Smoothness
4	Overhead railway, water bodies	150	0.2 / 0.8	0.4 / 0.6
3	Buildings	130	0.5 / 0.5	0.8 / 0.2
2	Imitation grass	75	0.9 / 0.1	0.9 / 0.1
1	Shadow, vegetation, elevated objects, asphalt, sand	25	0.7 / 0.3	0.5 / 0.5

Table 2. Segmentation parameters for UltraCam*D* data set

Regarding the aim of map updating into account, emphasis was set on the delineation quality and accuracy of buildings and correct detection of vegetation and impervious surfaces.
The 12-bit radiometric resolution of the HRSC image data allows to generate meaningful segments also in shaded areas and to comprise the smallest details contained in the data, which often results in more fractal segments. On the other hand errors in the DSM and resulting errors in the orthophotos of this data set are difficult to handle in the segmentation process, so that more segmentation levels have to be created.
Due to the photogrammetric process, the inevitable reduction from 12 to 8-bit in the UC data caused a loss of information especially in shaded areas and resulted in an inaccurate segmentation. The nDSM are used in both segmentation processes to distiguish multispectral similar data e.g. asphalt roofs and streets. They were weighted slightly higher than the multispectral layers in the building segmentation level.

3.2 Classification

The rule sets for both data sets are based on a process tree and a class hierarchy for a small representative training area. It could be easily transferred to other tiles. It is essential for a successful transformation that the algorithms contained in a rule set should be robust and reliable. Accordingly they have to be as simple as possible. One of the major problems to develop such robust rule sets is the heterogeneity of urban areas. The semantic contiguous objects are often divided in two or more separate, multispectraly varying segments. On the one hand geometry and texture can support class descriptions; on the other hand increasing complexity of algorithms has a negative influence on stability and separability of the concerned classes. (Oczipka, 2007).

In addition to the buildings the following objects were classified: parent class vegetation divided in the child classes trees, scrub and lawn, sealed and unsealed surfaces as well as elevated railway, water bodies and shaded areas. Therefore the classification results can be used not only as a basis for updating of building cadastral data but also in other monitoring applications, like calculation of sealing degree or proportion of vegetation. The classification results are also suited as basis for further detailed mapping, like tree crown detection, street inventory, gully or moving objects detection..

Classifying buildings
In the context of very high resolution of both data sets it was examined, how far the usage of nDSM can improve the classification of elevated objects particularly of buildings. In both rule sets the nDSM, representing the absolute heights above the ground, ware used in the segmentation and classification processes to divide sealed surfaces from roofs. It could be shown that the usage of nDSM have a crucial influence on the delineation quality as well as on the classification results. nDSM increase the segmentation quality of building objects and including the height information into the class descriptions stabilizes the classification results. The nDSM are indispensable for the analysis of urban areas and particularly of buildings. Using an adapted NDVI, the separation of high vegetation and buildings can be derived. This gives an example how two simple features like NDVI and absolute height can be used to extract buildings from image data, which made the rule set stable and reliable for the transfer on other image tiles.

Classifying other objects
The remaining class descriptions are based on spectral features and various ratios of the bands. Vegetation was extracted using an NDVI threshold. Geometric features are more suited to describe very large and homogeneous objects like water bodies or objects with typical geometric characteristics, e.g. railways.
The moving objects like cars, trains or ships in the HRSC data set make the classification of their surrounding classes like water and streets difficult, because they cause changes in their geometric characteristics. Due to the strongly different spectral characteristics they form distinct segments and can not be included in the surrounding main object. The problem of the moving objects could be solved with the help of the function "enclosed by class", which allowed to assign these objects to their neighbouring classes. Because the moving objects don't occur in the UC data their class description for classes asphalt and water bodies are more stable.

4. RESULTS

4.1 Accuracy Assessment

Both classifications were analysed using random samples. These samples were compared to a visual interpretation. A total of 1800 samples in the HRSC-AX data set and 5800 samples in the UC data set were selected. Comparing the accuracy assessment statistics show different results depending on the classes. Regarding the result on extracted buildings, Conditional Kappa for the class buildings using HRSC-AX data was 0,8923 and using UltraCamD data 0,9675 (see figure 3). The explanation for this difference is the higher geometric resolution and a resulting more accurate DSM in UC data. This provides more accurate delineation and classification results. Still, both data sets are suited for the object based classification. The Producer's and User's Accuracies are comparable good in both data sets. The classification of HRSC-AX data provides a higher overall accuracy due to its higher radiometric resolution and the improved segmentation in shaded areas (see Figure 4).

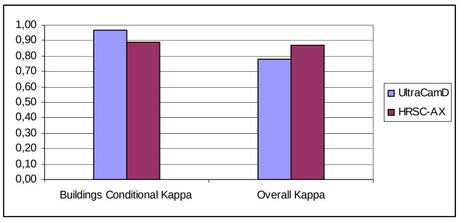

Figure 3. Kappa statistics for both data sets

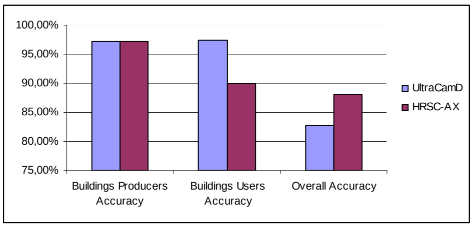

Figure 4. Accuracy Assessment statistics for both data sets

4.2 Updating maps

Further qualitative analysis was executed using the German cadastral geographic information system (ALK). It contains e.g. vector or point graphics and attributes of land parcels, buildings, streets and trees as well as administrative borders. (Senatsverwaltung für Stadtentwicklung, 2005). ALK data was exported to the shape format. The intersection of classification results and the ALK disclosed errors and problems in updating the system. A direct update of the maps in this system is usually not possible because the ALK is based on the base outlines of the buildings, a feature which is generally difficult to identify in an orthophoto due to occlusion effects.

Still, creating an intersection of the cadastral data and the classification results help to detect changes in build up areas and vegetation (Oczipka, 2007).

Intersections of classification results of the class buildings and the building layer of the digital cadastral map can be created in GIS. This analysis can be used to identify errors and changes in the digital cadastral map.

Figure 5 shows examples of UC image data, cadastral data (ALK) overlay, classification result (buildings) extracted from UC-data and detected changes.

Example A shows accurately detected removed building. In Example B the removed large building was correctly detected whereas the small building was incorrectly detected as removed due to inhomogenuos illumination conditions and trees. A wrong detection due to the almost complete vegetation cover is shown in example C. Although these intersections ease the map updating process, a fully automatic updating process is not possible due to the misdetections. Possible solution could be additional airborne laser scanner data and or measurement flights in winter.

Intersection of classification results and the ALK can also be used to monitor impervious surface within a block. Although automatic updating of maps is not possible, image analysis eases monitoring. The classification results can be easily exported to a geographical information system (GIS) as shape- or Autocad dxf file. The GIS can be used to quickly generate large scale maps in urban areas especially in developing countries and emerging markets, where new maps are essential for land management purposes, urban planning and monitoring.

5. CONCLUSION

All data sets used in this study allow very good classification results using object-based classification algorithms.

Best classification results for class building were obtained using the UC data, which are characterised by very good geometric quality. The very good overall classification accuracy of the HRSC-AX data – besides problems along building edges and with moving objects – results from its high radiometric resolution and spectral separability of the objects.

Ideal classification results can be expected with maximal radiometric resolution and very accurate DSM. A geometric resolution of 10cm or less is perfect in dense urban areas to accurately identify all objects of interest and detect changes.

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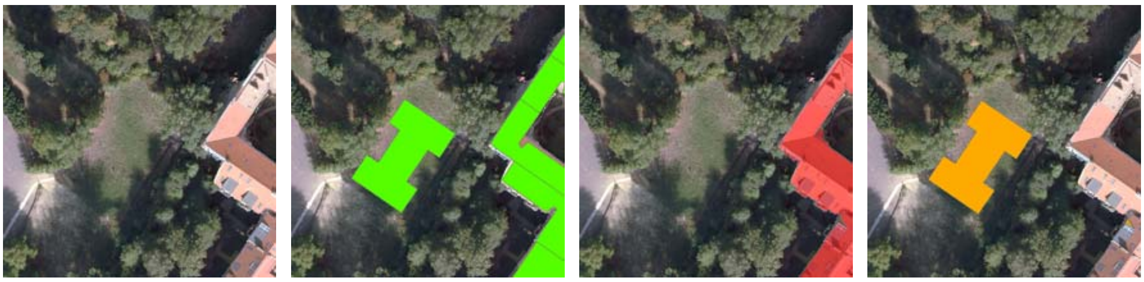

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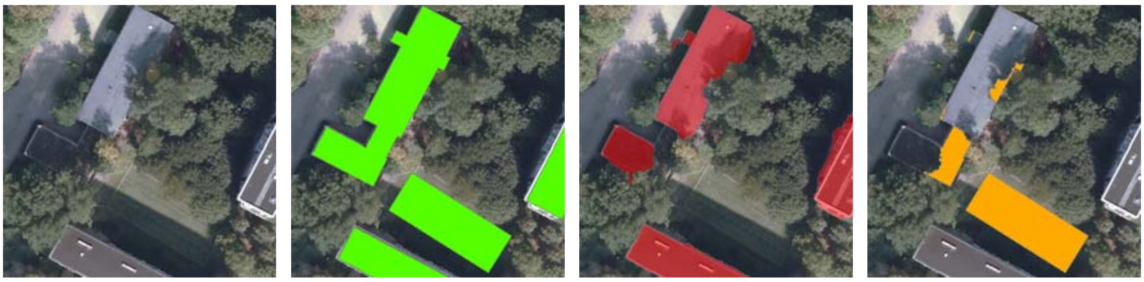

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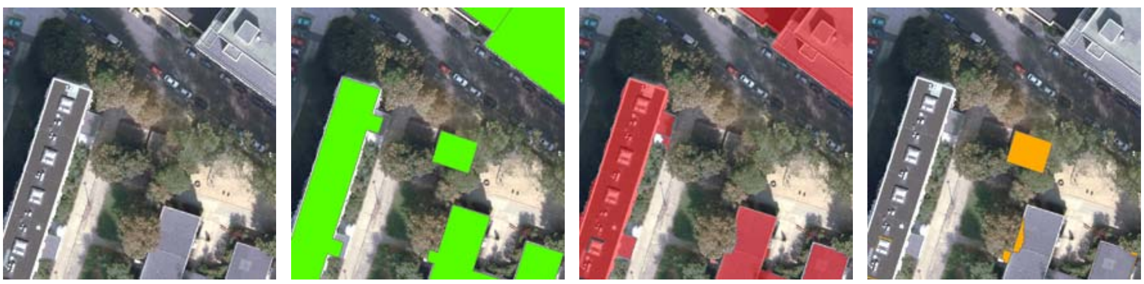

C)

Figure 5. Three examples (A – C) for change detection (from left to right): UC data set, cadastral data (ALK) overlay, classification result (buildings) extracted from UC-data, detected changes.