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Generation of Land Cover Maps Using High-Resolution Multispectral Aerial Cameras

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Abstract—**The generation of land cover maps has new advanced tools at its disposal. Besides new aerial cameras also new advanced processing tools are available. Elevations can be derived from images with high density and high positional accuracy. The combination of multispectral high-resolution imagery and high-density elevations for the automatic generation of land cover maps is discussed by means of a practical example. Imagery of a new aerial camera is used together with advanced software for generation of digital elevation models and for derivation of vegetation maps. These two products are the input for classification of land cover. A high degree of automation can be achieved. The obtained results of a practical example are checked with reference values derived from ortho-images in natural colour and from colour images using stereo-vision. An error matrix is applied in the evaluation of the results. The classification had an overall accuracy of 79%. Suggestions for the improvements in the applied methodology are made. The potential of land cover maps lies in updating of topographic databases, quality control of maps, studies of town development, and other geo-spatial domain applications. The automatic generation of land cover maps is also a trend in future mapping.**

Keywords-land cover map; classification; assessment; multispectral camera; map revision.

I. INTRODUCTION

Automated classification of aerial images has to be able to distinguish between objects on the ground and objects above ground. It is difficult to distinguish between buildings and parking lots or trees and grass. Land cover maps can be generated with a higher semantic accuracy when information on elevations is available. The updating of topographic databases will profit from such an approach. Of special interest are the built-up areas where most of the changes occur and where the actuality of the map data is very much in demand. Usually, high-resolution images are used for the generation of topographic databases. Aerial cameras have improved considerably in the last 10 years. The new generation of aerial cameras has features which will make the generation of land cover maps easier and more reliable. The processing tools have improved too. Besides the professional (expensive) software tools nowadays open source software tools (freeware) are available. All the necessary tools have to be tested whether they fulfil the requirements of the practice. It is the goal of this contribution to use imagery of a new aerial camera and to produce land cover maps. In contrast to traditional approaches (where only intensity values of images are used) elevations will be used in addition. Three-dimensional point clouds are generated from high-resolution images with a very high density and positional accuracy. Furthermore, the multispectral images of the camera allow an automated classification of vegetation and other features. This approach for generating land cover maps has the potential for a fully automated processing. The land cover maps can be the base for updating of topographic databases and for several other geo-spatial domain applications.

The accuracy of classification has to be assessed. From the gained experiences recommendations for the generation of land cover maps and the revision of topographic databases will be given. The paper starts with some general remarks on the revision of map databases. The new generation of aerial cameras and processing tools is presented afterwards. A practical example of a land cover map generation is then carried out using up-to-date software tools including some own developments. The results are assessed by means of statistical methods. A conclusion is drawn and possible future work is outlined.

II. GENERAL REMARKS ON THE REVISION OF MAP DATABASES

The revision of topographic databases requires detection of changes and errors. From the obtained results a decision has to be taken, in which way the renewal of the map database is to be carried out. It may be a completely new mapping, but mostly, an updating and correction of the existing information is carried out. This is done locally and in relatively small areas. It depends what type of data have to be revised. There are topographic databases in 2D and 3D. Sometimes only the important objects are updated, for example, buildings, roads, and trees. The process of updating should be an automatic process. This is at least the goal of today's map makers because stereo-plotting by operators is an expensive undertaking. Therefore, such work is often outsourced. In the past, a lot of efforts have been done to automate the detection of changes. Progress has been achieved using a semi-automated process. The automatically found changes will guide the operator to map new objects and to delete the obsolete ones. This may save some time for the operator, but the semi-automated process is not without costs, delays, and logistic problems. In order to automate also the mapping of the changes in 3D, the generation of a land cover map and of a digital elevation model (DEM) will be a first step. The automatic generation of land cover maps in 2D applies classification. The classification techniques use several attributes like spectral signature, texture, shape, etc. Also elevation has been taken as an attribute. If only elevations are used in classification, it is difficult to separate vegetated ground from parking lots and roads. The combined use of images **and** elevations is therefore a much better approach for the generation of land cover maps in 2D and 3D. The use of different data sources requires that all data are in the same reference system and that they have a good positional accuracy. Furthermore, all of the new data should be acquired simultaneously. Such conditions cannot always be fulfilled in practice. In addition, there are economic constraints that updating of topographic databases has to be carried out at low costs and in short time intervals.

In the past several studies have been carried out in the revision of maps, for example in [1]. In a project of the European Spatial Data Research (EuroSDR) different approaches were investigated [2]. Some research groups only used images, others used elevations only. The combination of images and elevations has also been suggested. Reference [3] used ortho-images of different times in order to derive areas of change. Reference [4] detected residential land use of buildings from lidar and aerial photographs through object-oriented classification. The event of a new generation of digital aerial cameras and of new processing software has changed the situation. It is therefore a goal of this paper to apply these new tools and to generate land cover maps automatically. The impact of such maps for the updating of topographic and other databases will also be discussed. Up-to-date data are the prerequisite in all geo-spatial domain applications. Land cover maps are often used for studies in town development. The changes in areas of buildings, traffic and vegetation over several years are studied in [5]. In that investigation the land cover maps are derived from vector maps and low-resolution satellite images. The applied classification of the images used intensity values only. The additional use of elevations of high density (as in this investigation) should result in more reliable results.

III. NEW DIGITAL AERIAL CAMERAS

With the appearance of new advanced digital aerial cameras the generation of land cover maps has new tools at its disposal. There are different types and models of aerial cameras; only three of the new cameras will be discussed in the following: the Hexagon/Intergraph DMCII 250, the Microsoft UltraCam Eagle, and the Hexagon/Leica Geosystems RCD30 camera. Details of the cameras are described in recent publications [6] [7] [8]. All three are frame cameras, and they can produce images of high resolution and high geometric quality. They are designed for mapping tasks. The produced images have different features; the major ones are listed in Table I. There is a considerable difference in the format of the output image. The RCD30 is a medium-format camera; the other two cameras are considered as large-format cameras. A larger format requires less flying in order to cover an area to be mapped assuming that the images of all cameras have the same ground sampling distance (GSD). The necessary length of the flight is an economic factor, and large-format cameras have an advantage in projects covering large areas. All three cameras can produce black&white, colour and false-colour images simultaneously. Newly designed lenses match the resolution of the sensor(s) and enable high image quality. The cameras are calibrated, and the obtained calibration data are used to correct the images in geometry and radiometry. Additional sensors for position (GNSS) and attitude (IMU) can be supplemented and will support accurate georeferencing of the imagery.

TABLE I. FEATURES OF THREE NEW DIGITAL AERIAL CAMERAS.

Features		UC Eagle	DMCII 250	RCD30
pixel size	[µm]	5.2	5.6	6.0
focal length	[mm]	80	112	50, 80
image size(in flight direction)	[pel] [mm]	13 080 68.0	14 656 82.1	6708 40.2
image size(across flight direction)	[pel] [mm]	20010 104.1	17216 96.4	8956 53.7
number of pixels per image	[MP]	262	252	60

Because the RCD30 images will be used in the following practical example some more details have to be mentioned. The colour images are produced from one CCD with Bayer filters. The infra-red band is imaged by a second CCD of the same high resolution (pixel size=6 µm x 6 µm). Image motion is compensated mechanically in two axes.

The output images are corrected for distortion, light-fall off of the lens and non-uniformity for dark signals. Two different lenses can be used without the need of re-calibration. In order to obtain images with GSD=0.05 m they have to be taken from 417 m above ground with a 50 mm lens. One frame will cover 0.15 km^2 on the ground. A gyro-stabilized mount can be used which will prevent big tilts of the imagery.

The potential of the mentioned new cameras with respect to automatically derived elevations has been investigated in [9].

IV. PROCESSING TOOLS

The generation of land cover maps from images requires various software tools. They reach from general image processing to dedicated software for photogrammetry, remotes sensing and GIS. One of the problems to overcome is the big amount of data. The work with small units may be necessary. One 64-bit computer with 8 Gb RAM (as it was at disposal in this investigation) is not an optimal processor. More computer power is necessary to solve the task for large areas. The many different tools are expensive if they have to be acquired from software vendors. Some software was available as freeware and open source. Such tools were preferred for this task. Some programming has been carried out using R-language, which is also available as open source.

V. Practical example

A practical example has been carried out in order to evaluate the proposed approach. A residential area in Switzerland with buildings, roads, paved paths, parking lots as well as trees, hedges and grassland was photographed. The size of the area is about one hectare. Errors and changes in topographic objects should be discovered. Of special interest are the errors and changes in the man-made objects.

A. *Outline of the methodology*

The land cover map to be produced should comprise the following classes: 'buildings', 'trees&hedges', 'grass', 'roads&parking lots'. These objects have certain attributes which will be used in the classification process. The used attributes are elevation and vegetation, which can automatically be derived from images. False colour images allow a separation of the image content in vegetated and non-vegetated areas using the Normalized Density Vegetation Index (NDVI). True colour images are used to derive a very dense 3D point cloud by means of matching corresponding image parts. The very dense point cloud has to be transformed into a Digital Surface Model (DSM). Filtering and editing will generate a Digital Terrain Model (DTM). The difference between the DSM and the DTM is the normalized Digital Surface Model (nDSM). NDVI data and nDSM data have to be in the same reference system. The DTM is also used for the production of a false colour ortho-image which is further processed to a NDVI map containing two classes (vegetation, non-vegetation). NDVI and nDSM information is then used to produce a land cover map. Fig. 1 depicts the steps in the production of the land cover map. Details of the classification process are also presented in a flowchart (cf. Fig. 2). Separation into ground and above ground or vegetated and non-vegetated areas is realized by specifying thresholds. At the position of the DSM points the NDVI attributes (vegetated or non-vegetated) are assigned. The classification of all DSM points with their attributes (ground, above ground, vegetated, non-vegetated) is then carried out and the result is plotted using different colours for the selected classes ('buildings','trees&hedges','grass','roads&parking lots').

B. *Data*

The used RCD30 imagery includes four bands (red, green, blue, near infrared) from which colour and false-colour images can be composed. Each image has about 6.4 Megabyte (Mb). The images were taken with a GSD of about 5cm. The images are geo-referenced and data of the geometric calibration (camera constant, pixel size) have been provided. As reference data a colour ortho-image has been generated. Furthermore, a map of building footprints was produced by digitizing from a stereo-pair of colour images.

C. *Applied tools*

For the generation of a 3D point cloud the Match-T program, version 5.4, of the Trimble/Inpho Company could be used [10]. Filtering of the data has been carried out automatically using filters of the professional program "DTMaster", version 5.4. Some manual editing was necessary and has been carried out by the same program. The orthoimages in false colours have been produced by Inpho's "OrthoMaster" program. The difference between the two elevation models (nDSM) has been calculated by a program produced in C-language. The generation of the land cover map was carried out by an R-program. Input was the nDSM and the NDVI map. The NDVI map was generated by the open source software LEOWorks, version 4.0 [11]. The produced land cover map was graphically improved by means of the Quantum GIS program, version 1.7.4, which is an open source Geographic Information System [12]. The assessment of the land cover map used the DTMaster program which enabled dynamic positioning to derived sample data.

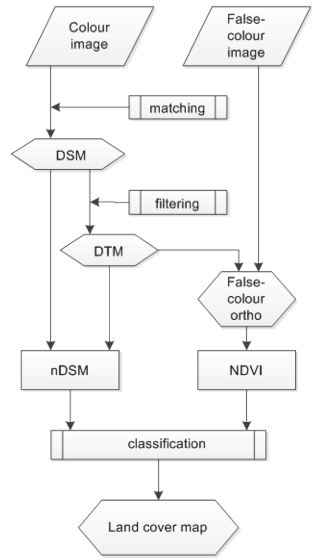

Figure 1. Steps in the production of a land cover map.

D. *Results*

The calculation of the 3D point cloud revealed a theoretical height accuracy of σ_Z = 0.16 m. The absolute accuracy of the DSM was determined by means of a few check points and resulted in $RMSE_Z$ = 0.22 m. The obtained nDSM had a relatively high density (up to 16 points/m^2). Its accuracy is estimated with $RMSE_Z \approx$ 0.3m. The NDVI map had two levels which were separated by a threshold of NDVI > 0.1. The threshold for separating low and tall vegetation or non-vegetated objects was selected with 1.0 m. The result of the classification using these two inputs is depicted in Fig. 3. The four classes are plotted by different colours and symbols and can be well separated from each other. This land cover map is georeferenced and can therefore be overlaid by a map of the building footprints (cf. right part of Fig. 4). The land cover map is based on the numerical output of the classification. Besides the spatial coordinates (Easting, Northing, elevation (Z_{DSM})), the difference in

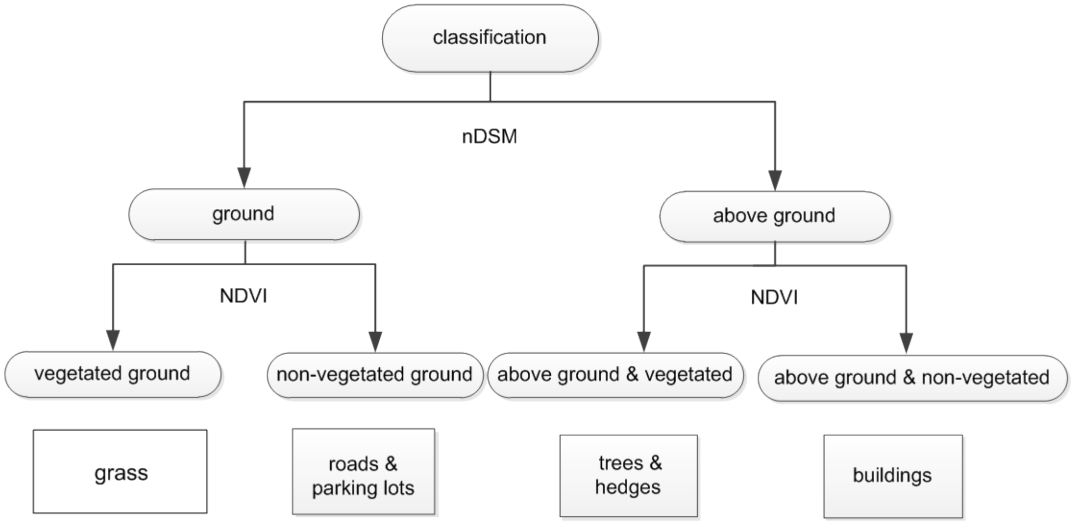

Figure 2. Classification flowchart.

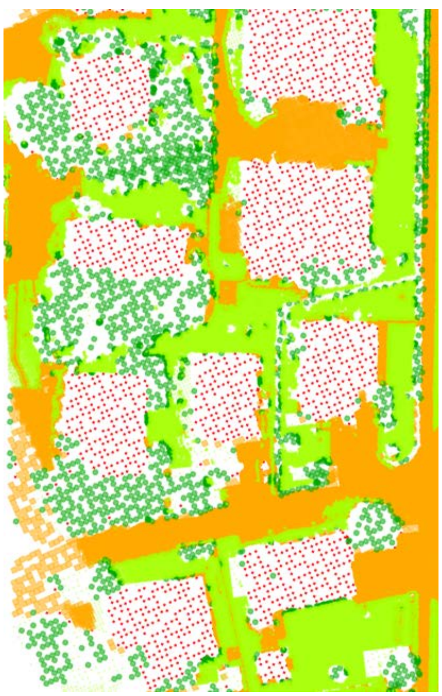

Figure 3. Result of classification. Legend: Red dots (‘buildings’), brown dots (‘roads&parking lots’), bright green dots (‘grass’), dark green dots (‘trees&hedges’).

elevation (dZ) between the DSM and DTM and the type of the point (class) are contained in the listing (cf. Table II). The list represents a “classified point cloud” and can be used for other purposes than mapping as well.

E. Checking of the classification accuracy

The classification can be checked visually. Fig. 4 depicts the input data together with the result. The overlay of building footprints with the land cover map shows pretty good agreement. The buildings and the trees are well separated. The shaded DSM and the land cover map display even small changes in elevations. For example, hedges can clearly be recognized in the land cover map.

TABLE II. EXAMPLE OF A “CLASSIFIED POINT CLOUD”.

Easting	Northing	Z	dZ	class
537129.2	5228938.6	486.5	0.2	“grass"
537129.2	5228938.7	488.5	2.3	"trees&hedges"
537144.5	5228987.4	486.4	0.0	“roads&parking lots"
537128.0	5228938.3	490.8	4.2	"building"

Errors in the separation between grass land and paths can be noticed in the shadows of houses. A few differences in the buildings can also be recognized. The manual mapping of the buildings used some generalizations with the result that balconies and extensions are missing. This is evident in the overlay of building outlines onto the land cover map.

The numerical assessment of the result can be done by means of reference values. These are derived by manual interpretation of a reference. For each class a number of DSM-points are randomly selected and compared with the reference. The accuracy of the classification is derived by applying an error matrix as suggested in [13]. The achieved classification accuracy is derived overall and for each class. It is distinguished between producer’s and user’s accuracy.

As reference, the colour ortho-image, which is based on the DTM, is chosen first. The classification has been verified at 91 randomly selected samples per class, altogether at 364 positions respectively. The sum of reference values in each class is listed as rows of the error matrix (cf. Table III). For example, at 91 sample positions of the class ‘buildings’ 43 were identified as ‘buildings’, 31 as ‘roads & parking lots’, 5 as ‘trees&hedges’ and 12 as ‘grass’ by means of a manual determination of the reference.

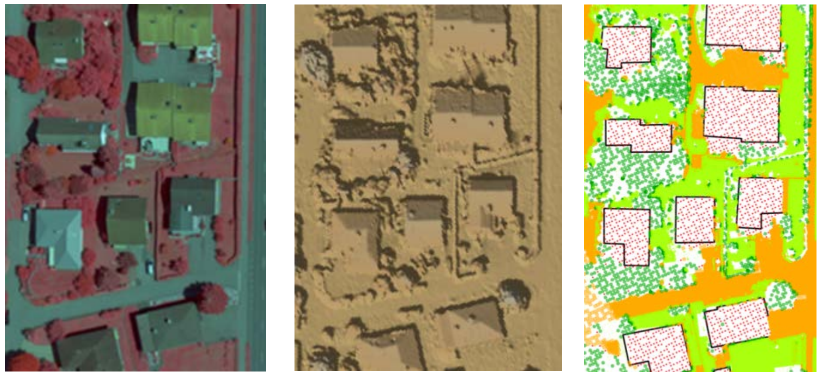

Figure 4. False colour ortho-image, shaded DSM and land cover map with overlay of building outlines.

TABLE III. ERROR MATRIX OF THE DERIVED LAND COVER MAP BY EVALUATION OF TRUE COLOUR ORTHO IMAGES.

	1	2	3	4	Σ
1 buildings	43	31	5	12	91
2 roads&parking lots	0	78	1	12	91
3 trees&hedges	1	6	50	34	91
4 grass	0	6	8	77	91
Σ	44	121	64	135	364

The overall accuracy of the classification is 68%. Of interest are the results for each class. The producer's accuracy for each class is 98% ('buildings'), 64% ('roads & parking lots'), 78% ('trees&hedges'), and 57% ('grass'). The user's accuracy of 'buildings' is 47%, of 'roads&parking lots' 86%, of 'trees&hedges' 55%, and of 'grass' 85%.

More accurate reference values can be obtained by means of stereovision using true colour images. The results are given in Table IV. The classification has been calculated again. The overall accuracy is 79%. The producer's accuracy for each class is 94% ('buildings'), 85% ('roads&parking lots'), 60% ('trees&hedges'), and 63% ('grass'). The user's accuracy of 'buildings' is 70%, of 'roads&parking lots' 92%, of 'trees&hedges' 59%, and of 'grass' 94%.

For the evaluation of the result the Kappa analysis is applied. Furthermore, the variance of Kappa (K) and the significance of the error matrix (Z statistic) are calculated by means of formulae published in [13]. The results are presented in Table V.

TABLE IV. ERROR MATRIX OF THE DERIVED LAND COVER MAP BY EVALUATION UNDER STEREO VISION OF TRUE COLOUR IMAGES.

	1	2	3	4	Σ
1 buildings	64	12	15	0	91
2 roads&parking lots	1	84	3	3	91
3 trees&hedges	3	1	27	15	46
4 grass	0	2	0	30	32
Σ	68	99	45	48	260

TABLE V. ERROR MATRIX AND RESULT OF KAPPA ANALYSIS.

Error matrix	$\hat{K}$	Variance	Z statistic
analysis #1 (ortho)	0.58	0.00100	18.2
analysis #2 (stereo)	0.71	0.00116	20.7

VI. DISCUSSION

The achieved overall accuracy derived from the 364 or 260 samples is 68% and 79% respectively. The user's accuracy is more important than the accuracy of the producer and will therefore be discussed further. The classification of buildings with 47% is poor when the evaluation is done by means of the true colour ortho-image. Much better is the result for 'roads&parking lots' and 'grass' (86% and 85% respectively). The class 'trees&hedges' is correct by 55%. When evaluation is done by means of colour images under stereovision (which requires the Z-coordinate of the sampled data) 'buildings' are classified with 70% which is a much better result. The classification of 'roads&parking lots' is achieved with even 92%. According to [14] the Kappa values (0.58 and 0.71) represent a moderate agreement between the classification and the reference data. The derived variances are small; the Z-statistic–value is far above 1.96 which represents a 95% confidence level. This means that the applied classification is significantly better than random. The comparison of the analysis #1 with analysis #2 shows about the same result for the Z-statistics (18.2 and 20.7). A statistical test indicated that the difference between the two Kappa values is significant. The results may be further improved by applying a bigger threshold than 1m in elevation or by additional steps in the elevations in order to separate more classes, for example shrubs, hedges, walls, etc. Also corrections for shadows and displacements of elevated objects in standard ortho-images could be considered. That means that true ortho-images instead of standard ortho-images could be used. Economic considerations will decide this question. The use of true ortho-images needs digital building models (DBMs), which are not generally available. The production of accurate DBMs is pretty expensive. The applied evaluation by means of stereovision is very useful.

VII. EVALUATION

In this paper elevation data of high density have been derived from aerial images. The applied high-resolution multispectral images also enabled an automatic classification of vegetation. By means of a combined use of elevation and vegetation data a land cover map could be produced with a high degree of automation. Such a map is the graphical output of a “classified point cloud” of high density. In the example the attributes of the point cloud were the spatial coordinates (Easting, Northing, and elevation), the normalized height and four classes (grass, roads and parking lots, trees and hedges, and buildings). The “classified point cloud” may have more classes when an extended classification algorithm will be used. For example, steps in the normalized height can differentiate various types of vegetation. In addition, water areas can automatically be extracted from the near-infrared channel of the multispectral imagery.

Decisive for good results of land cover maps is the quality of the applied imagery. A measure for the image quality is the so-called Point Spread Function (PSF). It is derived from edges within the image. The width of the PSF is considered as ‘scale factor of the effective pixel size’ [15]. This factor has been derived for one of the applied images with k=1.27 (average between centre and edge of the image). Such a value is close to values found for large-format aerial cameras [15]. In addition, the so-called Photo Response Non Uniformity should be checked. In tests of the applied imagery it was found that the intensity values were nearly the same in the centre and the edge of the image. This means that the classification of vegetation using NDVI has had prerequisites for good results. This could be confirmed by checking the vegetation map where only 6.4% errors were found. All of these investigations revealed good results for the applied imagery. The use of a medium-format digital camera (which is considerably less expensive than a large-format camera) is also a novel approach for the generation of land cover maps.

Digital Terrain Models, Digital Surface Models, as well as original 3 D points clouds may already exist for large areas. The generation of land cover maps may use such elevation data of existing databases. However, a quality control should be carried out whether the data are “fit for purpose”. High density, high positional accuracy, and completeness of the elevation data are prerequisites of the presented approach. Many other data in existing databases may be useful for the generation of land cover maps. The extraction of various data from existing databases and combining with new imagery is one of the big challenges in GIS technologies.

VIII. CONCLUSION AND FUTURE WORK

Land cover maps are a mapping product which has many applications. They can be used for the updating of topographic databases and for the quality control of topographic databases. Other applications are establishing of tree cadastres in municipalities and general studies in town development. The new tools like advanced aerial cameras and processing software packages make the automatic generation of land cover maps easier and more accurate. Especially, the use of elevations yields better results in the classification. The quality control by means of stereo-observations has to be used in order to receive reliable reference values. The described approach for the generation of land cover maps can be further improved by using information of existing databases. The number of classes can then be increased. Such an approach should be applied for large areas and comprise different types of urban areas.

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