EVALUATION AND INTEGRATION OF URBAN HEIGHT INFORMATION

INTO A DATABASE FOR RADIO PLANNING PURPOSES

Eckhard Siebe[*], Katrin Kaufmann[**]
[*]Mannesmann Mobilfunk GmbH, Germany
eckhard.siebe@d2mannesmann.de
[**]Interoute Telecom Deutschland GmbH, Germany
katrin.kaufmann@interoute.de

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ABSTRACT

With more than 10 million subscribers Mannesmann Mobilfunk is the leading GSM network operator in Germany. Due to the increasing number of subscribers in the D2 network and the resulting high traffic load, the network must be continuously adjusted. For planning radio networks topographic data is used. This includes demographic data, traffic data, information about land use and terrain height data.
For urban areas, where the network is planned using very large scales , details of the location and height of buildings is necessary. Up to now the building structure of more than 50 major cities has been derived from aerial image interpretation using photogrammetric procedures. In total, an area of more than 6000 sq km of building structure data has been identified and is available in a high spatial precision.
Since the production of such 3D-city models with manual photogrammetric methods and subsequent building-modelling is very time-consuming and costly, it is only applied to selected cities and up to now without modelling additional objects like trees.
However, also for smaller cities and the surroundings of metropolitan areas where information about the location and height of buildings and trees is currently still missing, data with improved accuracy will be needed for network planning in the future.
For this reason alternative methods with a higher extent of automation are gaining in importance. The acquisition of Digital Surface Models (DSM), i.e. precise information about the location and height of objects like buildings and trees, with methods using radar and by correlation techniques will be considered in this paper.
The objective of this paper is the detection of buildings and trees in Digital Surface Models (DSM) with methods of digital image processing. A radarinterferometrically derived DSM and a DSM derived from correlation methods applied to aerial images of the Duesseldorf area serve as a source for the object detection. Different filtering techniques are used to detect objects in the DSMs. The classification of the detected objects into buildings and trees is realized by the application of special methods on the according magnitude image of the radar data and the orthophoto.
In addition, information from ATKIS (Authorative Topographic and Cartographic Information System) is also used. The comparison of the results of the radarinterferometric data on the one hand and the correlated aerial image data on the other hand leads to an evaluation of the potential of radarinterferometric data for the application in radio network planning. For accuracy purposes the two approaches will also be compared with Mannesmann Mobilfunk˝s existing 3D-building data of that area.
Finally, the exemplary integration of the detected objects (buildings and trees) into the German ATKIS is shown. The ATKIS data will be used at Mannesmann Mobilfunk for several purposes, e.g. for controlling and enhancing the network quality. ATKIS which is still in development offers nationwide detailed land use information. In the first stage of realization, urban areas are represented by polygons. ATKIS does not yet contain single buildings or trees. Hence, a way is shown how information on buildings and vegetation can be added to ATKIS in the Mannesmann Mobilfunk environment in order to increase the information content of this data.

1 INTRODUCTION

The D2 mannesmann network is operated by Mannesmann Mobilfunk and is based on the GSM (Global System for Mobile Communication) standard. Currently, more than 10 million customers use the D2 network with its voice, data

and international roaming services. In order to continuously improve and optimize the network quality with the help of computer simulations a precise knowledge of influences of the electromagnetic wave propagation is necessary. With this information the cellular network can be adopted to the coverage and capacity demands of the market.
An economic network planning can only be carried out with the use of information technologies. The D2 network currently operates approx. 20000 cells all over Germany. The handling of such dimensions for planning purposes is only possible with computer based processes. To simulate the radio part of the network, complex physical models are implemented in special software tools. These models require a digital description of the real world which is relevant to the 900 MHz electromagnetic waves: land use data, building data, terrain elevation data, demographic data, traffic network data, and topographic maps.

2 3D CITY MODELS USED BY MANNESMANN

Within the last few years the demand for capacity in the hot spot regions has increased tremendously. One possibility to raise capacity is the introduction of smaller cell sites. However, because of the multiple use of frequencies and the resulting interference problems, the precise knowledge of the antenna locations and their surrounding topography is very important for the frequency reuse assignment.
In 1995, Mannesmann Mobilfunk started to place orders for generating 3D city models for selected German cities. Prior to this some feasibility studies were carried out in order to define methods, requirements and practicability. Up to now data for more than 50 cities with more than 6000 sq km in total has been generated with almost the same standard. Mannesmann Mobilfunk defines city structure data as geocoded digital elevation data in urban areas including the heights of building blocks. The buildings are generalized to the type of boxes. The data is available in vector as well as in raster form. In addition, precise ortho image mosaics help the planners in their daily work.

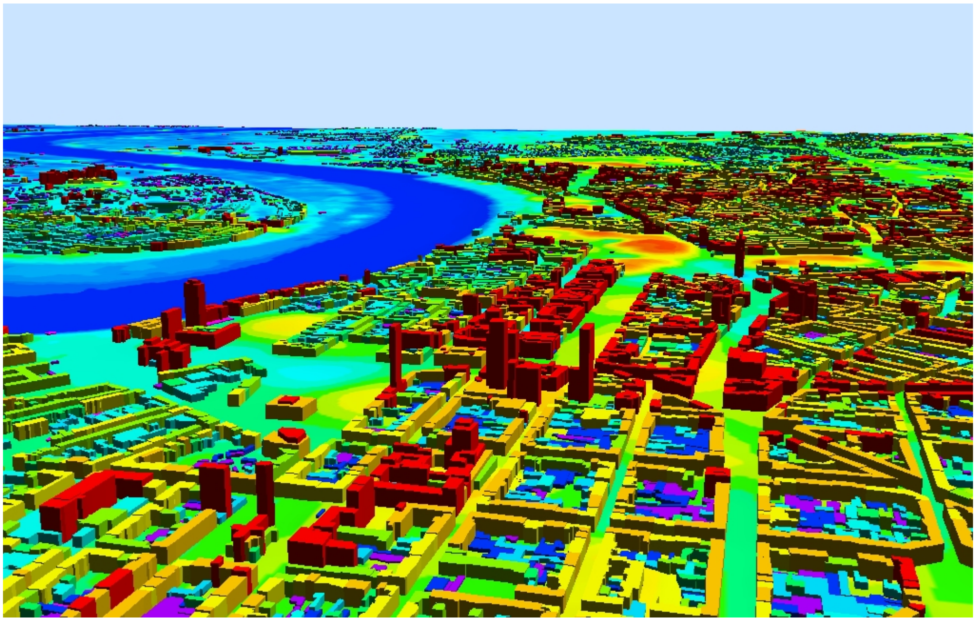

Fig. 1 shows a perspective view of downtown Duesseldorf and demonstrates the quality of the model.

3 DETECTION OF BUILDINGS AND TREES IN DIGITAL SURFACE MODELS

Since the production of such 3D-building models with manual photogrammetric methods and following building-modelling is time-consuming and costly, it is only applied to selected cities and up to now without modelling other obstacles like trees.
But also for smaller cities and the surroundings of metropolitan areas, where information about the location and height of buildings and trees has been lacking up to now, data with improved accuracy will be needed for network planning in the future.
For this reason alternative methods with more automated steps come to the fore. The acquisition of Digital Surface Models (DSM), i.e. precise information about the location and height of objects like buildings and trees, with methods using radar and correlation techniques will be considered in the next chapters.

3.1 Semi-automated Approach using digital aerial images

The following examinations are based on b/w aerial images from the Duesseldorf area of (approx. 15 x 15 sq km) taken in 1995 from a WILD RC30 camera with a scale of 1 : 15 000. The use of stereo correlation techniques within the program *OrthoMax* led to a base Digital Surface Model (DSM) with approx. 40% pixels of height values. Due to the dense urban area on the one hand and water and fields in the Rhine area on the other hand, this result is acceptable.
The global completion of the raw DSM requires several procedures within the *Erdas Imagine* GIS environment. First the outliers have to be eliminated by applying low pass filters. The completion will be done by using averaging filters repeatedly. Approx. 95% of the DSM is now complete. The remaining 5% will be filled by interpolation methods in a further step. A mean value filter is applied several times where at last only bigger continuous areas remain. These areas are e.g. shadows of tall buildings, meadows, flat roof buildings, water areas, etc.. In order to fill the gaps of the terrain height data, a procedure called “median of the smaller values” was developed. The basic idea of this concept is to define the terrain height excluding the existing building information. For this purpose a 100m by 100m filter is adopted. Within this filter the local maxima of the terrain and the buildings are defined. The median of the smaller values is a good approximation of the terrain height because the outliers have no effect. A complete DSM was generated this way. A comparison of the results with the reference terrain model shows a good correspondence, the mean difference was 1m, the standard deviation was ± 0.8 m.

The next step is to extract objects from the DSM. These objects are classified into buildings and trees with the help of ortho images. The object extraction can be separated into object detection and object classification. The basic digital terrain model (DTM) is generated using minimum and maximum filters successively. This is known as the procedure ‘opening’ (Baltsavias et al., 1995). In this study the size of the filters was changed depending on the landscape (open areas, forest, industry, residential areas, etc.). The result is a good approximation of the terrain height. The difference between the DSM and the DTM leads to a normalized surface model in order to detect objects via segmentation. Using a threshold value of 3m leads to objects or blobs which can most likely be defined as buildings or trees. In a last step, detected areas lower than a defined minimum size are removed and gaps in detected blobs are filled. Fig. 2 shows the different steps for detecting objects from a DSM.

Fig. 2. Object Detection Aerial Image

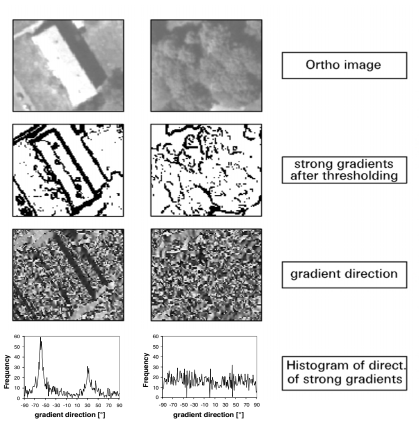

Fig. 3. Frequency Distribution of Buildings and Trees

For the classification of the detected objects the ortho image is used. A criterion for the distinction between buildings and trees is the distribution of the directions of strong gradients. In case of a building the frequency distribution of the gradients forms two maxima, in case of trees the distribution is random. For the determination of the directions of the gradients a threshold value was introduced. As shown in Fig. 3, the histogram of the direction of strong gradients varies between buildings and trees.
For the distinction between the two object types two criteria are used. Firstly, the standard deviation of the frequency distribution is used. Hereby we use the effect that the standard deviation of the frequency distribution is higher in buildings than in trees. Because the size of the object area has an impact as well, we secondly use the quotient of standard deviation and size for every object. Again a threshold,

varying with the size of the object, was introduced and finally leads to the distinction between the two object types.
The accuracy of this distinction will be discussed next. For the accuracy evaluation we selected 255 randomly distributed pixels and visually determined the objects within the ortho image. The confusion matrix explains the accuracy:

		Reference data (ortho image)		
		Object	Remainder	Σ
Result of the Object Detection	Object	**153**	17	170
	Remainder	6	**79**	85
	Σ	159	96	**255**

Table 1: Confusion Matrix for testing the Accuracy of Detected Objects

As shown in table 1, 153 pixels of 170 in total were recognized correctly as objects, 17 pixels were recognized incorrectly as objects. 6 pixels were not recognized as objects in the DSM, although they exist in the reference data. The reason for the incorrect determination of some objects results from errors in the stereo correlation, which leads to some extent to incorrect height points. Because not all of the blunders can be detected, the procedure "Opening" finds more objects than existing. This was often the case in the area of the Rhine meadows. Further errors are the result of the threshold value (only objects higher than 3 m and larger than 10sqm have been reviewed).

		Reference data (ortho image)			
		Buildings	Trees	Remainder	Σ
Result of the Object Classification	Buildings	**66**	9	10	85
	Trees	5	**73**	7	85
	Remainder	3	3	**79**	85
	Σ	74	85	96	**255**

Table 2: Confusion Matrix for testing the Accuracy of Detected and Classified Objects

Table 2 describes the accuracy of the object classification. 66 pixels classified as buildings correspond with buildings in the reference data , 9 pixels are classified as buildings, although they are trees in the reference data. The class 'trees' is recognized more precisely: 73 pixels are classified correctly, 5 building pixels are wrongly assigned as trees. These misclassifications have different reasons. Firstly, the spatial vicinity of buildings and trees often lead to a combined object 'building' (because of the larger spatial part). Secondly, buildings with non-rectangular edges are misclassified as trees due to their frequency distribution of the gradients.

In total, we can summarize that the overall accuracy of the object detection is 91 %. Due to classification errors the overall accuracy of the steps "object detection" and "object classification" is – with 85 % - slightly lower.
In the last working step we calculate the height of the detected and classified objects. Within the detected area we assign the median height as the representative height for the individual object. A comparison with the reference data for the buildings (reference data for the trees was not available) shows an accuracy of –1.1m with a standard deviation of ±2.6m. These differences result mainly from the median height assignment to all sizes of buildings which includes a higher inaccuracy in larger building blocks where the computed median value does not fit exactly to all parts of the building.

3.2 Semi-automated Approach using radar-interferometric images

For the detection of objects in radarinterferometric images we used data of the STAR-3i System from Intermap Technologies Ltd., Canada. The DSM and the corresponding radar-intensity images were derived by airborne one-pass interferometry with across-track configuration. The STAR-3i data was acquired on July 28 and 29, 1998 with a wavelength of 3 cm (X-band) and a spatial resolution of 2.5 m. The geometric accuracy of the radarinterferometric images is ± 3 meters, the height accuracy is ± 2 meters. These accuracy statements published by Intermap Technologies Ltd. are valid only for rural, not for urban areas. Generally the advantages of radar-interferometry are automated processing and independence from weather conditions.

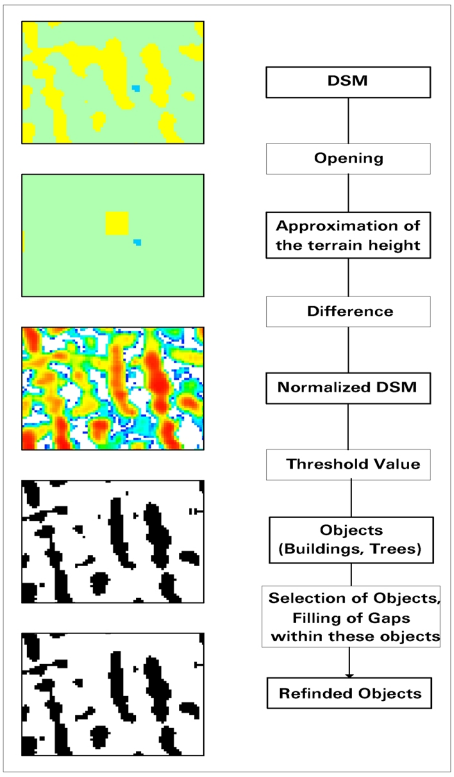

Fig. 4. Object Detection Radar Image

For this semi-automated approach using radarinterferometric images the same method was chosen as for the detection of objects in the aerial images. One reason for this was to guarantee a real comparison. First of all we generated a Digital Terrain Model by using the 'opening'. The sizes of the matrices for the minimum filters and the maximum filters were adjusted to the smaller spatial resolution of 2.5 m. The following subtraction of the Digital Surface Model and the Digital Terrain Model lead to the detection of blobs (see figure 4).

For the distinction of these blobs into buildings and trees (object-classification) we tested the use of the coherence data which shows the correlation between the two radar images. Different types of land use influence the correlation in different ways. Investigations on ERS-1 data have revealed that forested areas are characterized by lower coherence than fields (Derkum and Schwäbisch, 1997). Nevertheless, these results cannot be transferred to the present inquiry because we used One-Pass-interferometric and not Two-Pass-interferometric data like the ERS-1.

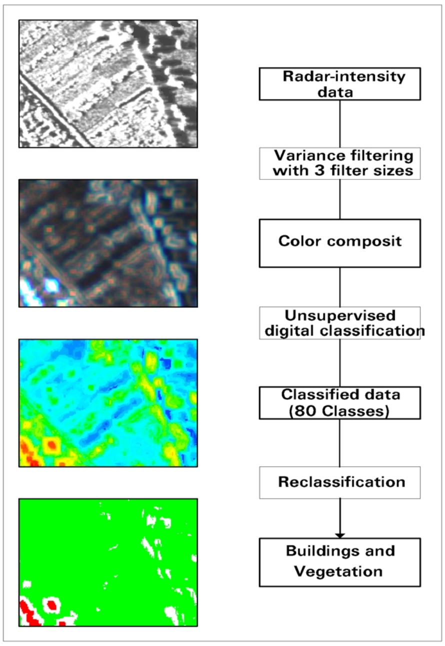

Fig. 5. Object Classification
Radar Image

Thus, we chose an unsupervised classification without using the coherence image for the object-distinction. The input data for the classification was calculated by using a variance-filtering with three different sizes of filter-matrices. Tests showed that the best results of the classification can be reached with filter sizes of 5 x 5 , 11 x 11 and 17 x 17 pixels. The unsupervised classification was realized with *ERDAS Imagine*. The classified dataset consisted of 80 classes from which the relevant classes 'buildings' and 'trees' and a third class (that represents all other objects) had to be derived. For this reclass we used the radar-intensity image and a topographic map for a visual recognition of buildings and vegetation. The result of the reclass was a dataset that contains buildings, vegetation and all other objects as a third class. This dataset was the base to decide whether the previously detected objects were buildings or trees. The decisive criterion for this was the most frequently occurring class.

		Reference Data (Ortho image)		
		Object	Remainder	Σ
Result of the Object Detection	Object	**138**	32	170
	Remainder	21	**64**	85
	Σ	159	96	**255**

Table 3. Confusion Matrix for Testing the Accuracy of detected Objects

		Reference Data (Ortho Image)			
		Buildings	Trees	Remainder	Σ
Result of the Object Classification	Buildings	**54**	10	21	85
	Trees	9	**65**	11	85
	Remainder	10	11	**64**	85
	Σ	73	86	96	**255**

Table 4. Confusion Matrix for Testing the Accuracy of Detected and Classified Objects

The steps ‘object-detection’ and ‘object-classification’ lead to a result that had to be checked. We used the same method as described above. Again, the ortho image was the reference for a comparison of 255 randomly distributed pixels. It should be noted, that the images were 3 years older than the radar data. Thus some changes were expected. Hence the result of the accuracy analysis could appear worse than it actually is. First, the accuracy of the step ‘object-detection’ shall be checked. The error matrix (see table 3) indicates that for 138 pixels of 170 in total the object-detection was successful. 32 pixels were recognized incorrectly as objects. Another 21 pixels were not detected as objects. In general, these errors are due to the inaccuracy of the DSM which was used for the object detection. Effects like lay-over, shadowing and specular reflection occur very frequently in urban areas and lead to an incorrect representation of the surface-height.

Table 4 shows the accuracy of both steps ‘object-detection’ and ‘object-classification’. 54 Pixels are classified correctly as buildings. 10 pixels which belong to the class ‘trees’ in the reference data were classified incorrectly as buildings. The accuracy of the object-classification of trees is higher. Thus 65 pixels are identified accurately as trees. Another 9 pixels were classified incorrectly as buildings although they are buildings in the reference data. The misclassifications of objects trace back to the reclass of the 80 classes to the relevant classes ‘buildings’ and ‘trees’. The assignment of the classes was problematic, because a clear distinction of buildings and trees was not always possible.
The overall accuracy of the result of the object-detection is 79.2 %, and 71.8 % for the result of object-classification.

In the next, step we calculated the height of the detected and classified objects as described above. Here we chose the maximal value within each detected blob because the DSM represents the real height of the buildings only in a few pixels and is generally too low. The accuracy of the building-height is –3.8m with a standard deviation of ± 2.9m.

3.3 Comparison of the results

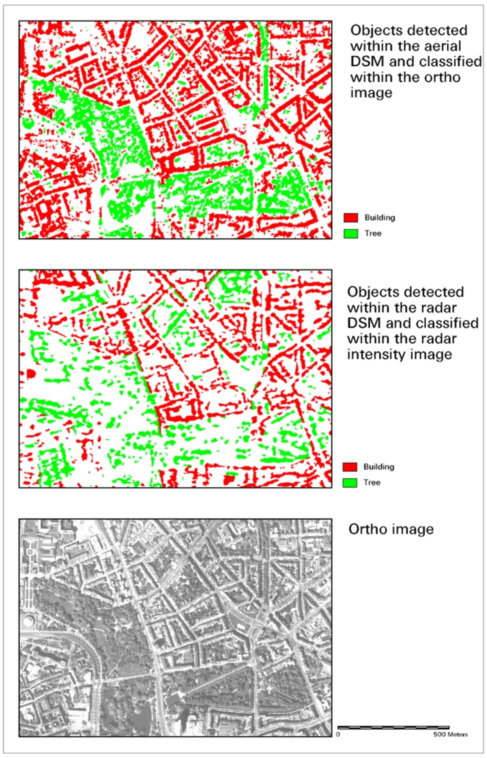

Fig. 6. Comparison of the Results of Object Detection and Object Classification

For a visual comparison of the result of the steps ‘object-detection’ and ‘object-classification’ see figure 6, where you can recognize a part of the city of Duesseldorf with a park called ‘Hofgarten’. A comparison with the ortho image shows that the blobs, that were detected and classified in the DSM derived by the ortho images, represent the real situation very well. The trees of the park and the building blocks of the city are recognizable. The blobs that were detected and classified in the radar data represent the reality more fragmentarily. Some buildings and trees were not detected at all, and the shapes of the detected buildings hardly correspond to the real shapes.
In both illustrations of the results you can find objects which are classified incorrectly. Especially, the round building at the left edge of the picture (Tonhalle) is striking. Because of its round shape it was classified by using the ortho images incorrectly as a tree. Using the radar data the result was a correct classification of this object as a building.

	Ortho Image-Data	Radar Data
Overall accuracy of object-detection	91 %	79.2 %
Overall accuracy of object-detection and object-classification	84.7 %	71.8 %
Accuracy of the building-heights	-1.1 m	-3.8 m
Standard Deviation	± 2.6 m	±2.9 m

Table 5. Comparison of the Accuracy Results

As table 5 shows, the overall accuracy of the detected objects in the ortho image data is 12 % higher than the overall accuracy of the detected objects in the radar-data. The same tendency is shown regarding the overall accuracy of the steps ‘object-detection’ and ‘object-classification’ together. Here, the accuracy of the result of the ortho image data is 13 % better than the result of the radar data. Also, concerning the accuracy of the object height the values calculated in the ortho image data are better than the values calculated in the radar data.

4 INTEGRATION OF BUILDINGS AND TREES INTO ATKIS

As a result of the described working steps we obtained two datasets, which contain buildings and trees detected and classified in the ortho image data on the one hand, and in the radar data on the other hand. For the exemplary integration of this information into ATKIS we chose the dataset, which was derived from radar data. The structure of the dataset had to be adapted to the structure of ATKIS. Thus, a raster-vector-conversion was necessary, which was realized under *ERDAS Imagine*. Buildings and trees are object types which are foreseen in the ATKIS structure in theory, but not yet realized. So we could used the given structure in order to store building heights and tree heights. In general, the integration was relatively simple to realize. Further tests have to be carried out in order to verify the additional advantage of this integration for the radio network planning process.

5 CONCLUSIONS

In this paper we demonstrated some semi-automated procedures for detecting and classifying objects like buildings and trees from aerial images as well as from radarinterferometric sources. Finally, we integrated exemplarily the additional information into the German ATKIS database.
The advantages of the radarinterferometric data are the lower costs and the immediate availability. However the accuracy is lower in terms of the height determination as well as the spatial detection. To what extent the lower accuracy has relevant influence on the radio wave propagation models, has to be investigated in detail.
In summary the procedures of detecting and classifying buildings and trees (either from aerial images or radar sources) are very promising. These methods can be a good help in creating realistic and up-to-date DSM for the needs of the radio network planning in mid-sized cities.

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