Tree Supported Road Extraction from Arial Images Using Global and Local Context Knowledge

Matthias Butenuth, Bernd-M. Straub, Christian Heipke, and Felicitas Willrich

Institute of Photogrammetry and GeoInformation (IPI)
University of Hannover, Nienburger Str. 1, 30167 Hannover
{butenuth, straub, heipke, willrich}@ipi.uni-hannover.de

Abstract. The quality control and update of geo-data, in this case especially of road-data, is the primary aim of the system, which is presented in the paper. One important task of the system is the automatic extraction of roads from aerial images. Structural knowledge about the scene, provided by existing information from a GIS database, is subdivided into global and local context knowledge. The "classical" global context approach was enhanced in such a way that additional context regions and relations were defined, mainly based on the different appearance of roads in these regions. Additionally, trees were added to the context model on the local level. After the extraction of rows of trees the road network is generated using this information as candidates for road segments. The rows of trees obtain evidence from the functional part of the road network model. Both extensions make the approach for road extraction more robust and more general, as is shown in various examples using 1:12500 panchromatic orthoimages.

1 Introduction

In this paper we describe our work on automated quality control and update of road data (i.e. freeways, main and side roads, paths) given in the German ATKIS DLMBasis. The ATKIS DLMBasis which is a part of the German Authoritative Topographic-Cartographic Information System (ATKIS), which is an object based digital landscape model of the whole country [4].
Germany has approximately 1.1 Mio. km of roads, and it is estimated that there are 10 - 15% changes per year. At the same time roads are probably the most important topographic object class of the country and it is of paramount interest to have very short updating cycles for roads, which can only be realized on terrestrial methods. Nevertheless, a periodic quality control, with the help of aerial imagery is an important safeguard against the deterioration of the database.

In a common project between the Bundesamt für Kartographie und Geodäsie (BKG, Federal Agency for Cartography and Geodesy) and the University of Hannover (IPI, Institut für Photogrammetrie und GeoInformation and TNT, Institut für Theoretische Nachrichtentechnik und Informationsverarbeitung) we develop a system for deriving quality description and update information from aerial imagery for geo-data, in this special case for road data. Our developments exploit the ATKIS scene description while extracting the roads from panchromatic orthoimages and comparing the extraction results to the ATKIS information [3]. The system has been

J.L. Crowley et al. (Eds.): ICVS 2003, LNCS 2626, pp. 162–171, 2003.

tested with 30 panchromatic orthoimages covering an area of 10 x 12 km^2 near Frankfurt/Main, Germany. The used orthoimages are available as standard products from the State Survey Authorities and have a ground resolution of 0.4 m. A similar project , called ATOMI, was accomplished at the ETH Zürich in cooperation with the Swiss Federal Office of Topography [16, 17].

In published work the use of additional knowledge for feature extraction from imagery is applied in several approaches: The use of global context for the extraction of roads was introduced in [1]. The focus in [6] is on the extraction of roads based on generic knowledge of road design rules and existing road data. The problem of the extraction of road intersections is addressed in [2] and [13]. Different models of intersections are used, for example simple intersections, roundabouts, complex and highway intersections. In [12] context information is used for additional knowledge for linear feature extraction. Different methods for extraction are categorized based on functionality, which enables the automatic process to choose the best one for a given application. Most of the approaches are designed to run in open, rural areas. There, the roads are often not occluded by buildings or trees and are relatively easy to detect, compared with European urban areas. In urban areas cars can be used as a reason for gaps in the road network, see investigations in [8, 9].

We use the approach developed at TU Munich by Wiedemann [13, 14] for the extraction of roads. The algorithm is optimized for open, rural terrain and images having a relatively low spatial resolution of about 1,5 – 2 m[1]. The adaption of the algorithm for our specific tasks is carried out by incorporating prior GIS knowledge, for example the road direction in the verification step and more specialized context information based on the ATKIS DLMBasis data during the change acquisition.

This paper deals with the strategy for automated quality control and update of road data by implementing global and local context knowledge: In addition to the road extraction we also extract rows of trees and combine both extraction results to generate the road network.

2 System Components

The quality control and update system of geo-data is designed to combine a commercial GIS as backend with fully automatic image analysis, it consists of three major parts (see Fig. 1).

1. A *GIS Component*, which basically selects and exports the object data from a database, and supports the manual post-editing of the results.
2. A *Process Control Component*, which selects the strategy for image analysis routines from the GIS data.
3. An *Image Analysis Component*, which automatically checks the existing geo-data (verification) and examines the imagery for additional data (change acquisition).

[1] We usually subsample the available orthoimages from 0.4 m to 1.6 m.

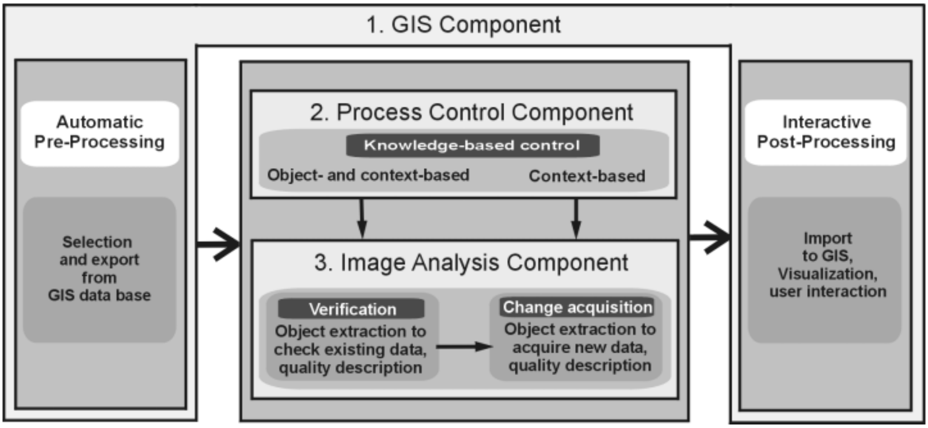

Fig. 1. Components of the quality control and update system

Here, we focus mainly on the implementation of the *Image Analysis Component*. We distinguish the *verification* and the *change acquisition* (Fig. 1): The verification means that existing roads of the database are investigated and a quality description is derived. Details and results of the investigations of the 30 black and white orthoimages of the test area are shown in [15]. Change acquisition means the extraction of new roads, which have not yet been stored in the database. Investigations in this subject-matter are the content of the paper, and some representive results of the test area will be shown.

3 Context-Based Strategy for Road Extraction

In this chapter we describe our work about the enhancement of the *Image Analysis Component* (see Fig. 1) of the quality control and update system in order to overcome two problems: The first problem we want to solve is the different appearance of the roads in the images depending on the global context. We enhance the strategy of using *global context knowledge* by means of additional priorknowledge about the landscape. The global context defines a frame for the extraction of individual objects, and makes the automatic analysis of imagery more feasible. An early implementation of this strategy is the multi scale road extraction approach of [1], in which three global context regions (open landscape, settlement and forest) were introduced. Here, we define additional global context regions: The *OpenLandscape* context region is subdivided into *AgriculturalArea* and *Grassland*, the *Settlement* is divided into *SmallStructures* and *BuildingArea* (Fig. 2). *SmallStructures* contains regions with narrow roads, e.g. allotments or golf courses. The main reason for this classification is, that a road looks different in these different context regions (cf. next chapter). In all cases the *Process Control Component* initiates an optimized knowledge-based parameter control for the algorithm, which extracts the roads inside these *global context* regions. The second problem, which we deal with, is that roads are occluded by trees leading to missing road segments. Therefore we have included a *Tree* in the scene model (Fig. 2). The whole graph representing the scene description can be decomposed into different sub-graphs. These sub-graphs are the *Landscape* (1) sub-graph, the *OpenLandscape* (2) sub-graph and the *Settlement* (3) sub-graph (cf. Fig. 2). The sub-graphs represent different parts of the landscape, but overlap where an object can appear in more than one sub-graph. In this case, however, the object "knows" from the context into which sub-graph it belongs. Therefore, models and methods which are relevant in this sub-graph can be chosen for the extraction. In previous work we have shown, that the regions of the landscape sub-graph can be automatically extracted from orthoimages [7], and how the settlement sub-graph can be used to simultaneously extract buildings and trees in settlement areas [5]. Here the landscape sub-graph is known a priori from the ATKIS DLMBasis, the decomposition of the scene into *AgriculturalArea*, *Grassland* and *SmallStructures*, is performed by using this knowledge.

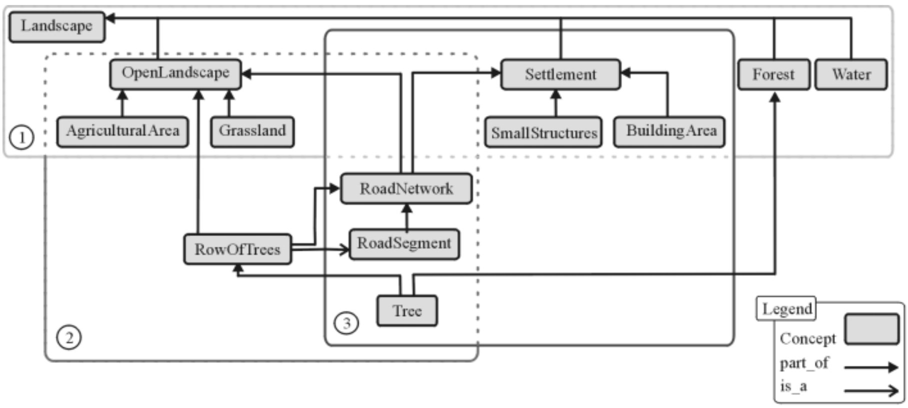

Fig. 2. Overview of the used global context regions and their relations to the extracted objects

An overview of the global context regions and their interrelations based on local context is given in Fig. 2. A *RoadSegment* is modeled as a line, having a higher or lower reflectance than the surroundings. Geometry is explicitly introduced into the model of the road by the assumption that roads are composed of long and straight segments. Roads are also described in terms of topology: the road segments form a network, in which all segments are topologically linked to each other. The extraction strategy is derived from the model and is composed of different steps. After line extraction according to [10] postprocessing of the lines is performed with several tasks in mind: (1) to increase the probability that lines either completely correspond to roads or to linear structures not being roads, (2) to evaluate the extracted line segments, (3) to fuse lines, e.g. from different data sets, (4) to prepare lines for the generation of junctions and (5) to construct a weighted graph from the lines and the gaps between them. The weights for the road segments are derived from radiometric and geometric criteria. From the weighted graph the road network is extracted by selecting the best paths between various pairs of points which are assumed to lie on the road network with high probability [13, 14].

In this project we have restricted ourselves using panchromatic images of a relative small resolution. Therefore, the hypotheses for *RowOfTrees* objects are created based only on greyvalues, the local greyvalue variance, and on the shape of the extracted regions. The skeletons of these regions are introduced as possible *RoadSegment*s into a weighted graph, with a low weight, from which the road network is extracted. A hypothesis is accepted only if it gives evidence to the road network, otherwise it is rejected. On the one hand this means, that only the evidence from the road network characteristic preserves the system from accepting wrong hypotheses. On the other hand the results show that this strategy helps closing gaps in the road network. The alternative would be closing these gaps without any evidence from the imagery.

Further information, which would make the extraction of the trees more reliable, would be for example a red and near infrared channel (used in [11]) and other textural descriptors [15].

4 Results of the Experiments

4.1 Control of Parameters Depending on Global Context

In this chapter we describe the advantages and possibilities in exploiting the *global* and *local context knowledge*.

We derive the knowledge about the *global context* from the objects in the ATKIS DLMBasis database, which is implemented in the *GIS Component* of the quality control and update system. We derive the object geometry and knowledge about the thematic attributes from the areal ATKIS objects. For this purpose the appropriate areal objects are selected from the database and merged to the different global context regions.

The knowledge-based control of the algorithm is embedded in the *Process Control Component* of the system, where an individual parameter set, depending on the different global context regions, is chosen automatically based on prior empirical investigations. With this additional information it is easier to accomplish the extraction of roads.

The applied road extraction algorithm [13, 14] is known to work reliably in the open landscape. In this context region the roads are normally not completely occluded as in forest, and only few buildings occur compared with settlement regions. The buildings make the extraction more complicated because – this is valid mainly for panchromatic imagery – they have a quite similar appearance as roads, and lead also to shadows, if they are located close to roads. We have investigated how the performance of the road extraction algorithm can be enhanced by means of subdividing the context region *OpenLandscape* in *AgricultureArea* and *Grassland* (see Fig. 2). Decisive for the definition of the context regions is the different appearance of the roads in different environments, e.g. high or low contrast between the road and the environment, or occlusions and shadows caused by trees or buildings. Another possible criterion is the varying road width and distance of crossings, e.g. in open landscape the distance is larger than in urban areas. Based on these characteristics, a refined control of the road extraction algorithm is necessary in order to reach a high degree of completeness under the boundary condition, that the correctness is as high as possible. In the approach of Wiedemann [13, 14] there are several possibilities to affect the underlying road model to optimize it to the appearance of the roads in each global context region. The best control sets were acquired through empirical studies by means of 30 orthoimages of the test area, representive results will be shown in this chapter.

Table 1. Part of the parameter sets for the context regions *AgriculturalArea*, *Grassland* and *SmallStructures*

Parameter	AgriculturalArea	Grassland	SmallStructures
contrast_high	40	15	40
contrast_low	20	15	20
line_width [m]	5.0	5.0	4.0
fuzzy_length [m]	5 50	5 50	2 40

The most important parameters of the road extraction module, which are influenced by the context regions *AgriculturalArea*, *Grassland* and *SmallStructures*, are shown in Table 1. The parameter *contrast_high* defines the upper border for the grey value difference between a candidate for a road pixel and the neighborhoods, *contrast_low* is the border with respect to other road pixels. The parameter *line_width* defines the width of a road, and the parameters *fuzzy_length* evaluates the length of a line segment with the help of the smallest possible value for a road segment, and the value which defines a membership of 1.

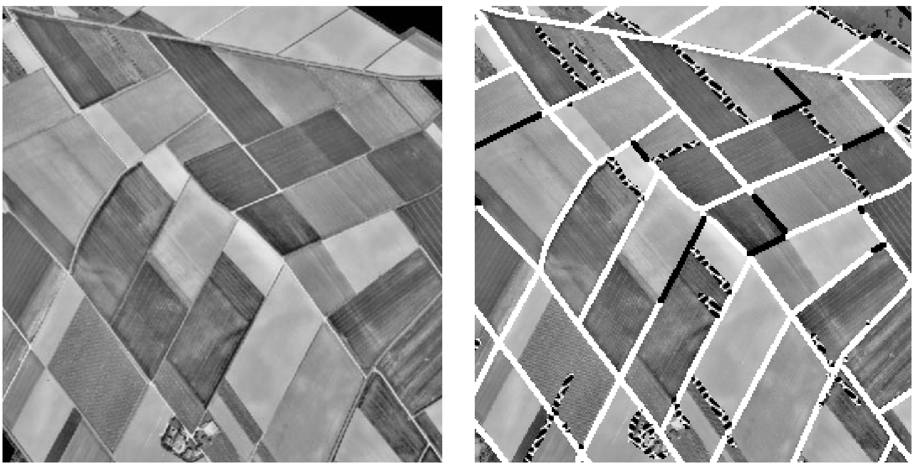

Fig. 3. Extraction result of the *AgriculturalArea*, shown is a quarter of a typical 2 x 2 km^2 orthoimage on the left side and the results of the evaluation superimposed to the reference data on the right side. White lines in the right figure correspond to correctly extracted roads, black lines to non-extracted roads, and dashed lines to incorrectly extracted roads

In Fig. 3 an example of the context region *AgriculturalArea* is shown: White lines depict reference roads, which were extracted by the system from the orthoimages, black lines depict the part of reference roads, which were not located by the system. The completeness of the extraction result in this typical orthoimage is 81% and the correctness is 72%, using the measures defined in [13].

False positives are often caused by borderlines between light and dark fields, because there are linear structures resulting from the borderline on the one side together with machine tracks on the other side. This fact leads to the relatively poor values for the correctness in this example.

Fig. 4. Extraction results of the region *SmallStructures*: Original orthoimage (top) and evaluation with reference data with unsuitable (center) and suitable parameter set (bottom); White lines correspond to correctly extracted roads, black lines to non-extracted roads, dashed lines to incorrectly extracted roads.

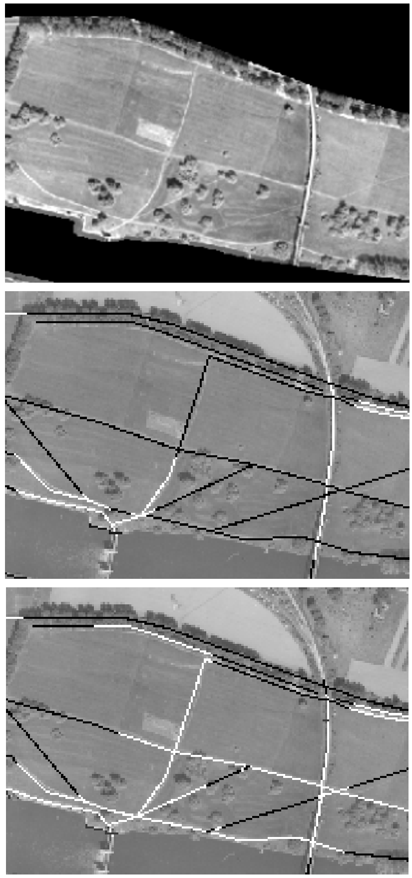

Fig. 5. Extraction results of the region *Grassland*: Original orthoimage (top) and evaluation with reference data with unsuitable (center) and suitable parameter set (bottom). White lines correspond to correctly extracted roads, black lines to non-extracted roads.

The influence of the refined parameter sets is demonstrated in Fig. 4 and 5: The extraction results of the orthoimage in the context region *SmallStructures* (Fig. 4) show a significant difference between the parameters used for the whole *OpenLandscape* and the refined parameter set. In this example the completeness of the road network increases from 36% to 55% and the correctness from 70% to 78%. Also for the context region *Grassland*, the quality of the results increases when refined parameters are used (see Fig. 5): the completeness increases from 49% to 64% and the correctness from 78% to 82%. However, the quality of the results in

Grassland and *SmallStructures* remains worse than in *AgriculturalArea*, because the contrast between the roads and the neighbouring areas is much lower, and there are significant occlusions by single trees and buildings.

4.2 Supporting the Road Extraction with Rows of Trees

In this section the combined extraction of roads and trees is described. There is one obvious local context relation between roads and trees, namely "*trees may occlude roads*". This leads to the demand that trees and roads should be extracted in two independent steps. The knowledge of *Forest* area (see Fig. 2) from the global context extraction gives us the possibility to learn the actual appearance of trees in the image data, assuming that the greyvalues and the texture of trees is independent of the context region.

In the *OpenLandscape* trees are often arranged in rows close to roads, these rows of trees are explicitly modeled in the ATKIS data model. In the feature catalogue one finds the following constraints for the object *RowOfTrees*. The data capture criteria according to ATKIS is: *"A row of trees has to be captured if it is longer than 200 m and lies along roads or is formative for the landscape"*. The extraction of instances of the object *RowOfTrees* in image space is executed as follows: First, elongated regions with similar greyvalue and textural appearance as *Forest* areas are searched inside the context regions of *OpenLandscape*. The skeletons of the resulting elongated tree/bush regions are selected according to their length as possible road candidates.

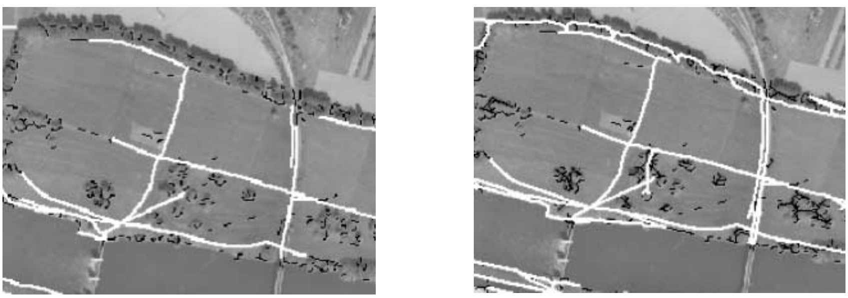

Fig. 6. Results of the road extraction without the support of trees depicted in the left image, the image on the right side shows the results of the road extraction algorithm together with rows of trees.

These skeletons are introduced into a graph as possible roads segments with relatively low weights, before the road network is generated. Then all the road segments were investigated in a fusion step, if they are close to each other than they are merged to one object. In this case the best hypothesis is chosen, and its weight increases.

The results of this process are for the context region *Grassland* depicted in Fig. 6. The road in the upper part of the image was not extracted due to the occlusions by trees (left image). Many connections in the road network could be closed (right image), as one can see near to the road junction in the upper-right part of the image. The short black lines depict extracted line segments, which were not accepted as road segments. The number of false positives is relatively low, and the improvement of the completeness is relatively high, which is obvious by a visual inspection of the two images in Fig. 6. The completeness of the road extraction supported by trees increases from 64% to 80%. The correctness decreases from 82% to 74%, because there were some false roads generated due to rows of trees.

5 Conclusions

We have shortly introduced our system for quality control and update of roads. The work described in this paper was focused on developments concerning the refinement of global context knowledge and the support of road extraction with rows of trees. Global context regions were refined by means of additional knowledge from a GIS database with the focus on the appearance of roads in these context regions. The global context region open landscape was subdivided into agricultural and grassland, the context region settlement in small structures and building area. The investigation has shown, that this strategy leads to better results in completeness and correctness. Furthermore, we have shown how the explicit modelling of disturbances can improve the performance of the system. Rows of trees were introduced as possible candidates for road segments with a lower weight in the road network generation step, in this way gaps could be closed.

Acknowledgement. The authors want to thank Christian Wiedemann for his support in the test phase of the road extraction software. The tree extraction part of the work was partly funded within the IST project CROSSES, the system development and testing was funded by the BKG.

References

1. Baumgartner, A., Eckstein, W., Mayer, H., Heipke, C., Ebner, H.: Context-Supported Road Extraction. In: Gruen, A., Baltsavias, E. P., Henricsson, O. (eds.): Automatic Extraction of Man-Made Objects from Aerial and Space Images (II) Birkhäuser Verlag Basel Boston Berlin (1997) 299–308
2. Boichis, N., Viglino, J.-M., Cocquerez, J.-P.: Knowledge Based System for the Automatic Extraction of Road Intersections from Aerial Images. In: International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, B3 (2000) 27–34
3. Busch, A., Willrich, F.: System Design for Automated Quality Control of Geodata by Integration of GIS and Imagery. In: International Archieves of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 2, Commission II (2002) 53–58
4. Endrullis, M.: Bundesweite Geodatenbereitstellung durch das Bundesamt für Kartographie und Geodäsie (BKG). In: R.Bill and F. Schmidt (eds.): ATKIS – Stand und Fortführung. Beiträge zum 51. DVW-Seminar am 25. und 26.9.2000 an der Universität Rostock, Schriftenreihe des DVW, Band 39, Verlag Konrad Wittwer, Stuttgart (2000) 39–52
5. Gerke, M., Heipke, C., Straub, B.-M.: Building Extraction From Aerial Imagery Using a Generic Scene Model and Invariant Geometric Moments. In: Proceedings of the IEEE/ISPRS Joint Workshop on Remote Sensing and Data Fusion over Urban Areas, IEEE Piscataway (2001) 85–89

6. de Gunst, M., Vosselmann, G.: A Semantic Road Model for Arial Image Interpretation. In: Förstner, W., Plümer, L. (eds.): Semantic Modeling for the Acquisition of Topographic Information from Images and Maps, Birkhäuser Publishers Basel (1997) 107–122
7. Heipke C., Straub, B.-M.: Towards the Automatic GIS Update of Vegetation Areas from Satellite Imagery Using Digital Landscape Model as Prior Information. In: International Archieves of Photogrammetry and Remote Sensing, Vol. XXXII, Part 3-2W5 (1999) 167–174
8. Hinz, S., Baumgartner, A., Mayer, H., Wiedemann, C., Ebner, H.: Road Extraction Focussing on Urban Areas. In: Baltsavias, E., Gruen, L., van Gool, L. (eds.): Automatic Extraction of Man-Made Objects from Arial and Space Images (III), A.A. Balkema Publishers Lisse Abington Exton (PA) Tokio (2001) 255–265
9. Hinz, S., Baumgartner, A.: Urban Road Net Extraction Integrating Internal Evaluation Models. In: International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 3A, Commission III (2002) 163–168
10. Steger, C.: An Unbiased Detector of Curvilinear Structures. In: IEEE Transaction on Pattern Analysis and Machine Intelligence, Vol. 20 No. 2 (1998) 113–125
11. Straub, B.-M., Wiedemann, C., Heipke, C.: Towards the Automatic Interpretation of Images for GIS Update. In: International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B2, Commission II (2000) 525–532
12. Wallace, S. J., Hatcher, M. J., Priestnall, G., Morton, R. D.: Research into a Framework for Automatic Linear Feature Identification and Extraction. In: Baltsavias, E., Gruen, L., van Gool, L. (eds.): Automatic Extraction of Man-Made Objects from Arial and Space Images (III), A.A. Balkema Publishers Lisse Abington Exton (PA) Tokio (2001) 381–390
13. Wiedemann, C.: Extraktion von Straßennetzen aus optischen Satellitenbildern. DGK Reihe C, No. 551 (2002)
14. Wiedemann, C., Ebner, H.: Automatic Completetion and Evaluating of Road Networks. In: International Archives of Photogrammetry and Remote Sensing, Vol. XXXIII, Part B3/2, Commission III (2000) 979–986
15. Willrich, F.: Quality Control and Updating of Road Data by GIS-Driven Road Extraction from Imagery. In: International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXIV, Part 4, Commission IV (2002) 761–767
16. Zhang, C., Baltsavias, E.: Improving Cartographic Road Databases by Image Analysis. In: International Achieves of Photogrammetry and Remote Sensing, Vol. XXXIV, Part 3A, Commission III (2002) 400–405
17. Zhang, C.: Updating of Cartographic Road Databases by Image Analysis. Ph. D. Dissertation, Report No. 79, Institute of Geodesy and Photogrammetry, ETH Zurich, Switzerland (2003)