AUTOMATED UPDATE OF ROAD DATABASES USING AERIAL IMAGERY AND ROAD CONSTRUCTION DATA

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ABSTRACT:

The update of geodata is an important task in order to ensure a high level of data quality in Geographic Information Systems (GIS). Today, this work is carried out mostly manually by an operator, who compares possibly outdated vector data from databases with remotely sensed imagery and/or other current information. In this paper we present a system for automated update of road databases using digital image processing for the extraction of roads from aerial imagery and topological analysis in order to optimize the whole process in terms of reliability and efficiency. In our context updating comprises road data verification and change acquisition. The main goal related to the verification is to call the operator's attention only to parts of the network where the automated process did not find evidence for a road. The aim of the change acquisition is to provide the operator with information about possible new roads to be added to the database.
For the verification the road extraction is executed twice: Firstly, with a strict parameter control ensuring the minimization of false positives and a subsequent evaluation which denotes roads from the database being accepted or rejected. In a second step a graph-based search algorithm detects connections which are missing for an optimized road network. If rejected roads are part of these connections they are checked again using a more tolerant parameter control. The road extraction is supported by the use of knowledge on the global level (whether the road is situated in rural, urban or forest areas) and information on the road geometry and its attributes.
The change acquisition is supported by the analysis of road construction data. Planned road objects are used to define the search space in the image. The applied strategy is similar to the preceding verification of existing road data.
Results of tests show the applicability of the proposed method for the update of topographic road databases.

1. INTRODUCTION

Geographic Information Systems (GIS) are used in many facets of our daily life. A majority – estimated to be about 80% – of the decisions taken by public authorities and private industry are made using spatial data. The more this kind of data is used the more important the question regarding its quality becomes. In our context quality is understood to comprise completeness, positional accuracy and correctness of the attributes for each object, and additionally temporal correctness. For more details regarding these quality measures in general and the efforts being made for their standardization refer to (Joos, 2003).
The aim of our work is to increase the efficiency of quality control and update of road objects in the ATKIS DLMBasis. Our current approach on updating comprises road data verification and change acquisition, however, we do not yet deal with the incorporation of the changes into the database. ATKIS stands for Authoritative Topographic Cartographic Information System and represents the German national geo-spatial core database. The DLMBasis (basic digital landscape model) contains the data of the highest resolution approximately equivalent to a topographic map 1:25000[1].
Today, quality control is done manually: A human operator compares the road objects from the database with an up-to-date orthoimage. In our work we want to automate this process: The main idea is to carry out an automatic road extraction in the image. Road attributes and context information from the database are used in order to support and optimize the extraction process. Currently, we restrict ourselves to panchromatic orthoimages with a ground resolution of 0.4m, since such imagery is readily available for the whole country. If the road extraction algorithm finds evidence for a road in the neighbourhood of a road object from the database, this road is accepted, and rejected otherwise. In the following step a human operator can focus on the rejected roads only, resulting in significant time savings as compared to the traditional process. The designed system has been tested with 30 orthoimages covering an area of 10 x 12 km^2 near Frankfurt/Main, Germany, results were presented in (Willrich, 2002).
In (Gerke et al., 2003) an improvement of this approach was introduced. It focuses on a graph-supported verification of the existing road database aiming at a higher efficiency of the whole verification procedure.
In this paper we first give an overview of the topology-based verification and show experimental results. Secondly, we focus on the change acquisition, namely the detection of new roads, not yet contained in the database. The idea is to incorporate road construction data for this purpose: The verification of such data leads directly to a description of roads to be added to the database.
In the next sections we first give an overview of related approaches and describe our system for road verification (section 3) and change acquisition (section 4). Finally, some results show the feasibility of the introduced approaches.

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2. PREVIOUS WORK

2.1 Knowledge-based road extraction

Every road extraction algorithm is based on an appropriate object model. Road models which are too generic have the disadvantage that their radiometric and geometric properties also fit to other linear features. If, on the other hand, the chosen model is too rigorous, a number of roads will not be extracted. One possibility to overcome this problem is to incorporate additional knowledge about the object itself in terms of local and global context (Baumgartner et al., 1997).

Local context defines the interrelationship between single objects. In aerial imagery roads may be occluded by buildings or trees. If this knowledge is considered and if appropriate object extraction algorithms exist, one may benefit from local context and derive a better extraction result. For example, Hinz and Baumgartner (2000) use objects found in urban areas such as road markings, cars or buildings to enhance the road extraction in these regions. Butenuth et al. (2003) use extracted rows of trees in rural areas to close gaps between extracted road sections.

Global context defines the environment in which the object is situated. In certain environments objects have certain properties, e.g. a road network in urban areas is much denser than in rural areas and single road segments are often shorter. Moreover, the global context influences the appearance of the objects in aerial imagery: For instance there are much more occlusion by buildings in urban areas than in rural areas.

Bordes et al. (1997) use a nation-wide road database to derive geometry (e.g. curvature and length) and semantic information (type of road and number of lanes) of road objects to optimize the road extraction and to exclude other objects. Additionally, global contextual knowledge is incorporated from the database. Although the objects in the database are modelled in a small scale (1:100000) the information is sufficient to be used for road extraction at a larger scale.

In (Wallace et al., 2002) another approach is applied. As the underlying system is designed to extract more linear object classes than roads, it first carries out a linear object extraction and then classifies these objects according to additional knowledge, derived from a database.

In the Swiss ATOMI-project (c.f. Baltsavias 2002, Zhang and Baltsavias 2002) the topographic database Vec25, consisting of road objects digitized from maps 1:25000 is being generalized and thus geometrically refined by extracting roads automatically from aerial imagery. Object information and global context knowledge from the database as well as local context knowledge obtained from object extraction algorithms is used to optimize road extraction.

In summary, a large number of road extraction algorithms have been suggested in the literature. Recently, trends using more prior knowledge in the form of object models, context, topology, and more diverse input images such as color, near infrared and – especially in urban areas – also height layers can be observed. Nevertheless, virtually none of the algorithms has found its way into practice, perhaps with exception of the work carried out in ATOMI. It is our goal to design and implement a reliable quality control module for road databases, incorporating the latest research findings from image analysis and being useful for practical applications.

2.2 System for road verification and change acquisition

Our system for automated road update includes three modules: the Automatic Pre-Processing module, the Main Automatic Processing module and the Interactive Post-Processing module (c.f. Fig.1).

In the Automatic Pre-Processing phase the *GIS Component* exports the road objects to be verified from the database, including their geometric descriptions and attributes, such as road width. Moreover, the knowledge about the global context contained in the ATKIS DLMBasis is obtained. The Main Automatic module consists of the *Process Control Component* and the *Image Analysis Component.* The first component is a communication layer between the GIS and the latter component: It makes the information from the database available for object extraction in an appropriate manner. The *Image Analysis Component* itself consists of the Verification and the Change acquisition module. Finally, the *GIS Component* is used again to support interactive post editing. In the following we first describe the graph-based road verification (Verification module) and then focus on the Change acquisition module.

3. GRAPH SUPPORTED VERIFICATION OF EXISITING ROAD DATA

The Verification module is designed to detect commission errors (a road from the database does not exist in the reference orthoimage) and to check the positional accuracy of the roads

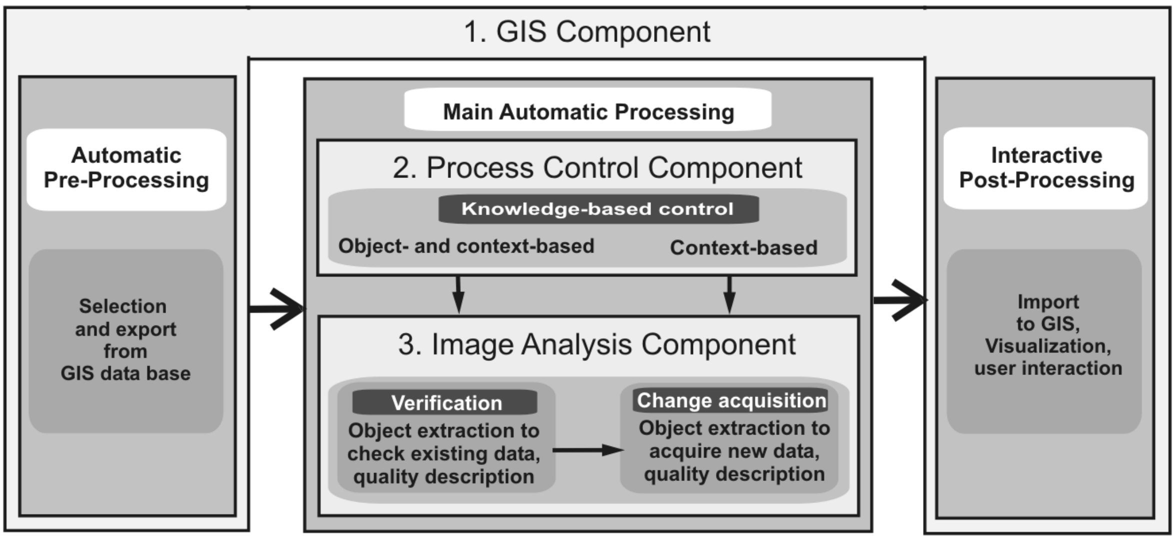


Figure 1. System Overview

from the database. In order to solve this task a region of interest is defined for each road object from the database. More precisely, a buffer around the vector representing the road axis is defined, the buffer width complies with the geometric accuracy of the road object and the road width attribute in the ATKIS database. If the latter value fails a plausibility test or is not available at all, a predefined value is taken. Subsequently, an appropriate road extraction algorithm to be executed in the image domain of the buffer is selected. The selection in the *Process Control Component* (c.f. Fig. 1) includes an optimized control of the parameters considering the knowledge on the given context region.

We are currently using the road extraction algorithm as introduced by Wiedemann (Wiedemann, 2002; Wiedemann and Ebner, 2000). This approach models roads as linear objects in aerial or satellite imagery with a resolution of about 1 to 2 m. To meet this demand the orthoimages are resampled to 1.6m. The underlying line extractor is the one introduced by Steger (1998). Note, that in our current implementation lines must be either brighter or darker than the surroundings. A step-model (one side of the line is darker, the other one is brighter) is not available at this point. The initially extracted lines are evaluated by fuzzy values according to attributes like length, straightness, constancy in width and constancy in grey values. The evaluation is followed by a fusion of lines originating from different channels. In our case we are using panchromatic imagery, but the line extractor is applied twice: Firstly, using a bright line model (line is brighter than the background) and secondly using a dark line model (line is darker than the background). The last step in road extraction as applied in the Verification module is the grouping of single lines in order to derive a topologically correct and geometrically optimal path between seed points according to some predefined criteria. The decision, if extracted and evaluated lines are grouped into one road object, is taken corresponding to a collinearity criterion (allowing a maximum gap length and a maximum direction difference).

All significant and important parameters for road extraction can be set individually. We adapted the described road extraction software to our specific tasks, especially by applying individual parameters for the given context areas and the extraction for each road object separately.

As proposed in (Gerke et al., 2003) this road extraction algorithm is applied twice: In the first phase a strict parameter control (mainly relating to contrast thresholds and gap length to be bridged automatically) is used. The road objects accepted in this step are called *accepted I roads*, the rejected ones are denoted *rejected I roads*. In the second phase a more tolerant set of parameters is chosen. The idea is to minimize the number of false positives in the first phase. This is important in order to ensure the reliability of the verification as automatically accepted roads should doubtlessly having been found in the image. The selection of roads having been rejected in the first phase but to be checked again in the second phase is based on a topological investigation of the given network.

In Fig. 2 an overview on the Verification module is given. Our approach on road verification enhancement is based on the assumption that a road network connects any two points (called *start-nodes* below) in a way that distance is minimized. In other words we search for the shortest path between two *start-nodes*, based on the ATKIS DLMBasis road database. Although we do not know if the network given in the database is fully correct, we can use it to formulate connection hypotheses.

In the ATKIS DLMBasis the topology of the road network is implicitly given as adjacent road objects share the same node points. Therefore, it is rather simple to derive a graph description from the road database. In the next step *start-nodes* are selected. A *start-node* must have at least one adjacent *accepted I* road as those nodes are supposed to be already confirmed junctions in the network. To minimize the computing time, we also require a *start-node* to have at least one adjacent *rejected I* road.

The next step consists in searching for the shortest path between *start-nodes*. For this purpose we apply the A*-Algorithm (Duda and Hart, 1973). The edges of the given graph are weighted with the length of the corresponding road object. Therefore, the shortest path between two *start-nodes* equals the shortest road connection. All *rejected I* objects which are part of those shortest road connections are subsequently checked again.

This described procedure has the following effect: All *rejected I* objects which are on both sides directly connected to *accepted I* objects are chosen for the second examination. Moreover, if a combination of several road objects connects adjacent *start-nodes* in the way that the total length of the connection is shorter than the connections given by *accepted I* objects, all *rejected I* roads being part of this shortest connection are also chosen for the second examination phase.

It should be pointed out that the application of the tolerant parameters for the whole scene from the beginning may lead to an unacceptably high number of false positives. Just the support by means of topological considerations allows to apply a more tolerant parameter control. The example in Fig. 3 shows a typical scene, containing roads in rural context. The upper

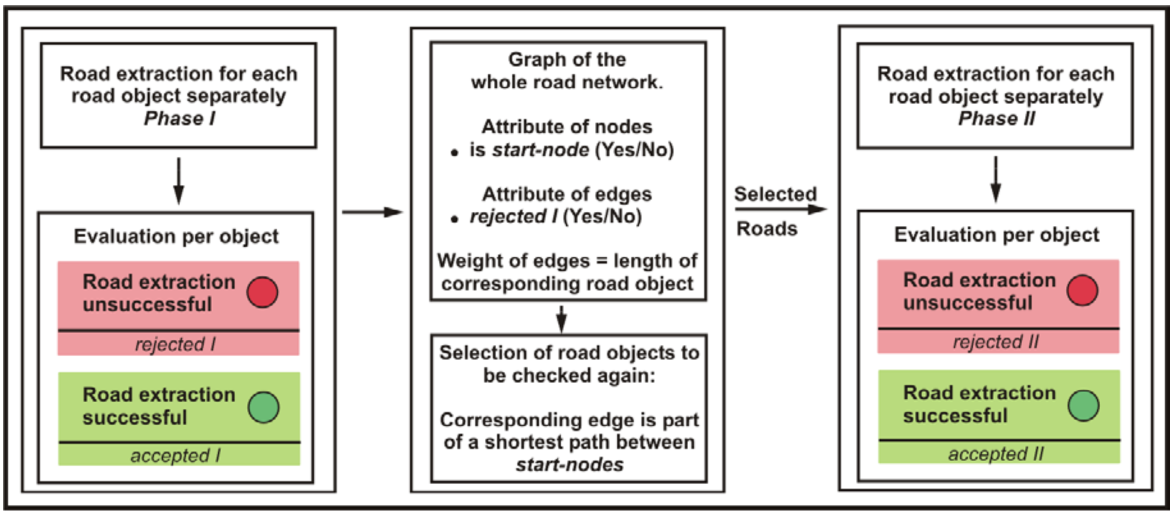


Figure 2. Overview on the Verification module

image shows the network of accepted roads after the first evaluation phase and the lower image the respective network after the second phase, i.e. the network of finally *accepted* roads.

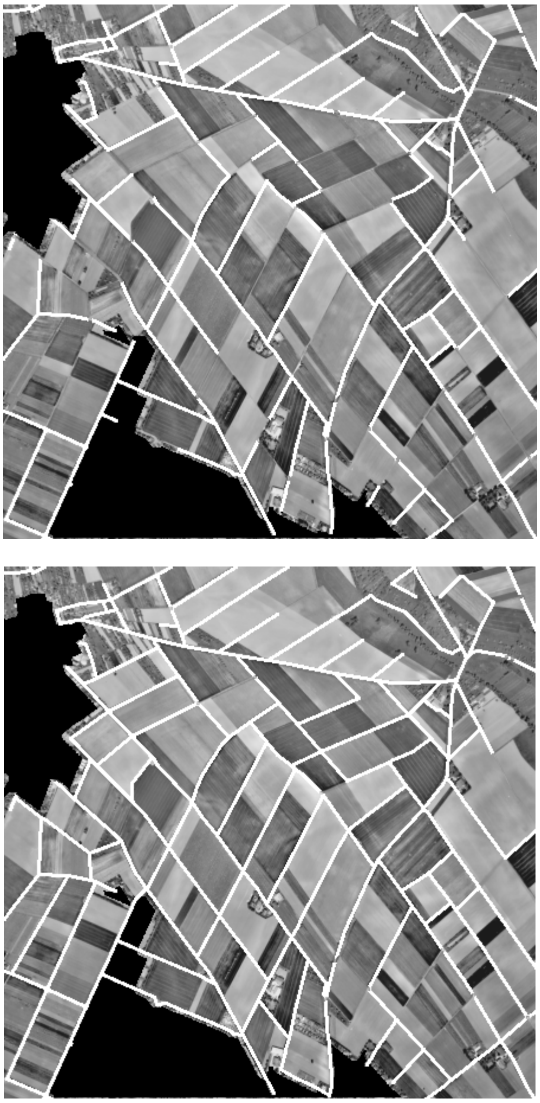


Figure 3. Example-image and the superimposed *accepted* roads (in white) after first (top) and second (bottom) evaluation phase. Settlement Areas (black) are not considered

The final network is much denser than the *accepted I* – network. An analysis of the finally *rejected* roads shows that several causes may lead to the *rejection*: a) The contrast is very weak; in some cases even a human operator could not decide whether a road exists at this position or not, b) Lines are not extracted due to the missing step-model implementation, c) Roads are hidden by dense rows of trees. Often, parts of roads are not extracted due to one of the mentioned reasons. In these cases the resulting gap is too large to be bridged automatically, even in the tolerant second examination phase. An extensive examination of the verification results is given in (Gerke et al., 2003).

4. CHANGE ACQUISITION BASED ON A VERIFIED NETWORK AND ROAD CONSTRUCTION DATA

In contrast to the Verification module the Change acquisition module aims at detecting omission errors, i.e. roads which can be found in the image but which are not yet contained in the road database.

4.1 Problem definition

Omission errors can be caused by two main reasons: Firstly, the road already existed when the database was created or last updated, respectively maintained, but the operator forgot to capture the road or did not see the necessity to do so. The important fact here is that the missing road is part of an existing network, its age is probably similar to the adjacent roads. The second reason for omission errors is that the road was not built or completed when the road database was last updated, i.e. the road is newer than the database.

We distinguish between these two reasons, because the strategy for detecting missing roads differs. Often, the radiometric properties of missing roads and the local context depend on the age of the road: if the road missing in the database has an age similar to the adjacent roads, the contrast conditions will probably be similar, too. Furthermore, objects influencing the local context (e.g. occlusions by trees) are also comparable.

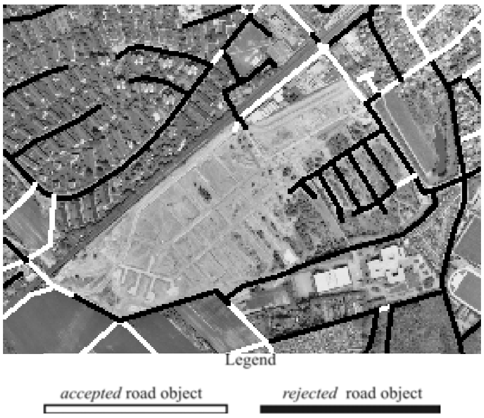
The main reason for building new roads is to make accessible buildings within new settlement areas and to connect such areas to the existing road network. New roads are also built to relieve existing roads from too much traffic (such as a new road bypasses a village).

These considerations relate to the question, to which context region these new roads belong. In new settlement areas roads are often the first objects which are completed and it usually takes years until a dense urban structure is created – consider for example the time for a tree to grow. Bypass-roads in most cases are planned outside settlements. These thoughts lead to the assumption that the new roads we are interested in are situated in open terrain (called rural context area in out work).

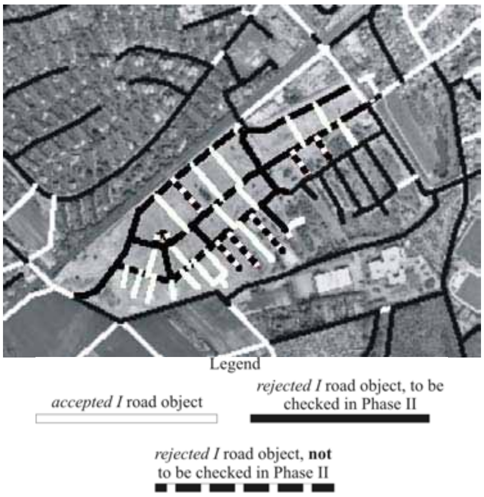
Another reason why we aim to distinguish between newly built-up roads and roads which have a similar age than the adjacent road network is that in the near future in Germany the construction data for new roads will be are available in a standardized digital format. In this case one can reduce the task of change detection to a verification of construction data. In the subsequent text we concentrate on the latter case of using road construction data for change acquisition.

4.2 Strategy for analyzing road construction data

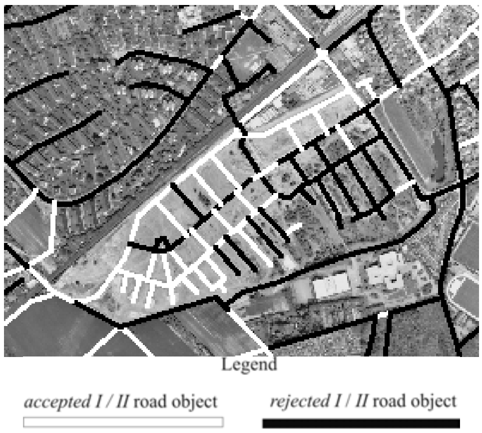
The approach for using road construction data in order to detect missing roads in the current ATKIS DLMBasis is similar to the verification as introduced in chapter 3. The road extraction algorithm is also applied twice: Firstly with a strict parameter control in order to ensure a minimum number of false positives, and secondly with a more tolerant parameter control for the automatic road extraction in order to close gaps detected by the graph based analysis. This graph analysis refers to the given road construction data and the already *accepted* road network. In the following we call the merged graph of *accepted* road objects from verification and the graph of road construction data *analysis* graph. It is assumed that the graph of road construction data is connected to the road network in the ATKIS DLMBasis, i.e. the *analysis* graph is a contiguous graph. Similar to the approach for road data verification it is assumed that every node inside the construction data is linked to every other node in this graph by the shortest possible path in the *analysis* graph.



Final result of Verification module



Result of Phase 1: Change acquisition by verification of road construction data and selection of objects for Phase 2



Final result of Change acquisition module

Figure 4. Exemplary result from the Change acquisition module

In Fig. 4 the results for a test-scene are shown. In the upper image the final result from the Verification module is given. The image in the middle shows the result from the first phase of Change acquisition by verification of the road construction data. The roads selected for the second examination phase are depicted in solid black. In the last image the final result is shown.

In this example problems which may arise when construction data is analyzed are showing up. The roads are still under construction and therefore a lot of these roads where not detected even with the tolerant parameter control, mainly because the contrast is too weak for automatic road extraction. On the other side disturbances by neighbored objects (local context) do not exist.

5. RESULTS

Two requirements have to be satisfied by the Verification module: Firstly, it has to be reliable, i.e. finally accepted roads must actually be correct. Secondly, the number of false negatives (road rejected although it can be found in the image) should be minimized in order to reduce the post-processing time for the human operator.
Similar demands hold for the Change acquisition module: If a planned road can be found in the image it should be denoted as *accepted* and therefore give a hint to the operator to include this object into the database. On the other side it should be avoided that a planned, but not yet built road, is depicted as *accepted*.
In order to check if these requirements are fulfilled, we tested the Verification module for ten scenes, containing 2356 road objects in rural context. Regarding the Change acquisition module we took a closer look to the test area depicted in Figure 4. For a more detailed overview of the results from the Verification module, refer to (Gerke et al., 2003).

	accepted = 1659	*rejected* = 697
Correct = 2265	1623 (68,89%)	642 (27,25%)
Not correct = 91	36 (1,53%)	55 (2,33%)

Table 1a. Verification: evaluation-result

	accepted = 26	*rejected* = 11
Correct = 23	19	4
Not correct = 14	7	7

Table 1b. Change acquisition: manual evaluation-result

We compared the result from the respective modules with a reference dataset and listed the interesting parameters. The results are shown in Tables 1a and 1b: For each *accepted* object we checked whether it is correct or not, and we did the same for the *rejected* objects. Ideally the elements beside the main diagonal should be zero. The values in the *accepted*/not correct-field are an indicator for the reliability of our approach (the smaller the value, the more reliable are the results). As was mentioned before, reliability is a crucial factor because accepted roads are not further checked in subsequent processing steps. The number *rejected/correct* roads should of course also be small, however this value is not as important as the first one, because such roads are subsequently checked by the human operator.
When interpreting the results given in Tables 1a-b one has to bear in mind that the definition of a road is sometimes rather vague – think of a small pathway between two fields.
In our examples for the Verification module the percentage of incorrectly accepted roads is about 1.5% and thus acceptable, whereas the number of incorrectly rejected roads is about 27%. Regarding the Change acquisition the percentage of incorrectly *accepted* roads is about 19%, the percentage of incorrectly *rejected* roads is about 11%. It has to be kept in mind that the test area is a very difficult one due to the low contrast conditions, and that the number of objects being analysed by the Change acquisition module is not high. The results have been presented to show the general applicability of the method, the actual percentages are not very significant.

The essence of this small test is that our verification results are convincing, only about 1.5% of the roads where incorrectly *accepted* and about 27% were incorrectly *rejected*.
Regarding the Change acquisition, a detailed analysis of the performance of the introduced approach is not feasible on the basis of the presented example. In the near future we will extend the investigations for this module and test it with other data.

6. CONCLUSIONS

In this paper we have introduced a graph-based approach for road verification and change acquisition from aerial imagery. The background of this work is to design a system, which supports a human operator in updating an existing road database. Two main issues are of interest: Firstly, the automatic process has to be reliable, i.e. if a road from the database can not be found in the image data the system has to reject it. Secondly, the system has to be efficient, i.e. it should automatically extract as many correct road objects as possible.
A topology supported road verification and change acquisition is presented, which combines the results of a very strict road extraction module (phase I) with the road extraction in the given imagery using a more tolerant parameter control (phase II). The choice of road objects to be checked in the second phase is based on an algorithm which tries to find the shortest connections between reliably extracted roads.
The detection of new roads, not yet included in the database, is supported by construction data. As the shown examples of the Change acquisition module indicate, further investigations with respect to the generalisation of the used approach are necessary.

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REFERENCES

Baltsavias, E.P., 2002. Object Extraction and Revision by Image Analysis Using Existing Geospatial Data and Knowledge: State-of-The-Art and Steps Towards Operational Systems. In: *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences,* Xi'an, Vol. XXXIV, Part 2, pp. 13-22.

Baumgartner, A., Eckstein, W., Mayer, H., Heipke, C. and H. Ebner, 1997. Context-Supported Road Extraction. Automatic Extraction of Man-Made Objects from Aerial and Space Images (II), Editors: Gruen, A., Baltsavias, E.P. and O. Henricsson. In: *Proceedings of the Centro Stefano Franscini*, Ascona, Birkhäuser Verlag, Basel, pp. 299-308.

Bordes, G., Giraudon, G. and O. Jamet., 1997. Road Modeling Based on a Cartographic Database for Aerial Image Interpretation. In: *Semantic Modelling for the Acquisition of Topographic Information from Images and Maps*, Editors: Förstner, W. and L. Plümer, Birkhäuser Verlag, Basel, pp. 123-139.

Butenuth, M., Straub, B.-M., Heipke, C. and F. Willrich., 2003. Tree Supported Road Extraction from Arial Images Using Global and Local Context Knowledge. ICVS 2003, Graz, Editors: Crowley, Piater, Vicze, Paletta, Lecture Notes in Computer Science 2626, Springer, pp.162-171.

Duda, R.O. and P.E. Hart., 1973. *Pattern Classification and Scene Analysis*. Wiley, New York, pp. 482.

Gerke, M., Butenuth, M., Heipke, C. and F. Willrich., 2003. Graph Supported Verification of Road Databases. In: *ISPRS J. Photogrammetry & Remote Sensing, Theme Issue "Integration of geodata and imagery for automated refinement and update of spatial databases"*, to appear.

Hinz, S. and A. Baumgartner., 2000. Road Extraction in Urban Areas Supported by Context Objects. In: *International Archives of Photogrammetry and Remote Sensing,* Amsterdam, Vol. XXXIII, Part B3, pp. 405-412.

Joos, G., 2003. Standardization of Data Quality Measures. In: *Proceedings of the 2nd International Symposium on Spatial Data Quality*, Hongkong, Editors: Shi, W., Goodchild, M.F., and Fisher P. F., pp. 205-209.

Steger, C., 1998. An unbiased detector of curvilinear structures. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 20 (2), pp. 311-326.

Wallace, S.J., Hatcher, M.J., Ley, R.G., Priestnall, G. and R.D. Morton., 2002. Automatic Differentiantion of Linear Features Extracted From Remotely Sensed Imagery. In: *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Graz, Vol. XXXIV, Part 3.

Wiedemann, C., 2002. Extraktion von Straßennetzen aus optischen Satellitenbildern. DGK bei der bayrischen Akademie der Wissenschaften, Reihe C Dissertationen, Heft 551, München.

Wiedemann, C. and H. Ebner., 2000. Automatic Completion and Evaluation of Road Networks. In: *International Archives of Photogrammetry and Remote Sensing,* Amsterdam, Vol. XXXIII, Part B3, pp. 979-986.

Willrich, F., 2002. Quality Control and Updating of Road Data by GIS-driven Road Extraction from Imagery. IntArchPhRS (34), Part 4, Ottawa, pp. 761-767.

Zhang, C. and E.P. Baltsavias., 2002. Improving Cartographic Road Databases by Image Analysis. In: *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Graz, Vol. XXXIV, Part 3, pp. 400-405.