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QUALITY CONTROL AND UPDATING OF ROAD DATA BY GIS-DRIVEN ROAD EXTRACTION FROM IMAGERY

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ABSTRACT:

Describing the quality of digital geodata in a geodatabase is required for many applications. We present our developments for automated quality control of the German topographic vector data set ATKIS using images. The automation comprises automatic cartographic feature extraction and comparison with ATKIS data, which both are triggered by additional knowledge derived from the existing scene description. To reach an operational solution the system is designed as an automated system which admits user interaction to perform a final check of the fully automatically derived quality description of the data.

1. INTRODUCTION

1.1 Motivation

Digital geodata have increasingly gained in importance for a large number of tasks in planning, documentation and analysis. Today in many application areas digital topographic databases are available und comprise area objects like settlement, agricultural and forestry area as well as linear objects like roads, railroads and water ways.

Describing the quality of digital geodata in a geodatabase is needed for many applications because the results of any analysis highly depend on the quality of the input data used for it. Therefore the Commitee Europeen de la Normalisation developed the model of ISO 19113 defining Meta Data Standards to describe data quality (cf. CEN, 1994). It especially involves the quality criteria completeness, logical consistency, positional accuracy, thematic accuracy and temporal accuracy (cf. Joos 2000). Deriving such a quality description is a prerequisite for revealing errors and inaccuracies in the acquisition, or to discover areas where an updating has to be performed.

In practice among others aerial and satellite imagery is used for acquisition, quality control and updating of geodata. In general these tasks are performed manually by a human operator. As for many application tasks the most expensive part is to supply the basic data an efficient procedure for data acquisition and for quality control is required to ensure that the production process of geodata provides the desired quality with justifiable expenditure. The use of digital imagery has the potential to at least partially automate data acquisition and quality control and thus to speed up and to reduce the costs of data production and maintenance.

For many users geo-databases containing the road network are of especially high interest as one can easily imagine from applications like e.g. in car navigation, route planning and logistics (cf. Fuchs et al., 1998). This is reflected by the high effort in acquisition of a road database which is carried out for car navigation purposes and by the postulated highest up-to-dateness of some few month for the transportation network within the Authoritative Topographic-Cartographic Information System (ATKIS) in Germany.

This paper presents a procedure for automated quality control of roads in the object-based digital landscape model ATKIS DLMBasis being the ATKIS data of the highest resolution approximately equivalent in content to a topographic map 1:25000. The quality description is derived by comparing ATKIS data to imagery which represents reality of the covered scene. The developments result from a pilot R&D project of the University of Hannover initiated and jointly conducted by the Bundesamt für Kartographie und Geodäsie (BKG, Federal Agency for Cartography and Geodesy). The developments are planned to be integrated in the daily production process and thus have to reach an operational solution.

For quality control we compare the vector data to standardised digital black and white orthophotos. Besides the vector data of the DLMBasis these raster data are part of ATKIS and are used because they are area-wide available in Germany.

Automation of the quality control using imagery comprises different subtasks to be solved: a. the extraction of roads and b. the comparison of the extracted roads with the existing data. Our developments especially deal with the exploitation of the scene description given by ATKIS while solving these subtasks. The system is designed to increase the efficiency of the quality control by combining automatic procedures with user interaction in a GIS environment. User interaction still is an indispensable supplement as one cannot expect any fully automatic process to reach the reliability which is required for an operational solution (cf. Lang and Förstner 1996, Gülch 2000). It helps to bridge the remaining deficiencies of the automatic procedures.

1.2 Related Work

Automatic feature extraction from aerial images has been a major activity of international research in photogrammetry and computer vision during the last decades (e.g. Förstner et al. 1999, Baltsavias et al. 2001). Although there is much success in cartographic feature extraction experience has shown that algorithms only give good results if applied to well-defined application areas. All approaches need additional knowledge which can more easily be formulated for restricted situations than for general applications.

GIS data can provide a valuable source of additional knowledge (cf. Vosselman 1996) and can be used to stabilize the image interpretation tasks as algorithms for object extraction can benefit from the information contained in the GIS. This however requires a close and well-defined interaction between image analysis and GIS. Knowledge based systems have proven to be a suitable framework for representing knowledge about the objects and exploiting it during the recognition process.

Quint and Sties (1995) incorporate knowledge derived from maps into a semantic network modeling environment to support image interpretation in urban area. DeGunst and Vosselman (1997) use knowledge-based techniques for the interpretation of road networks. Object-specific knowledge is derived from standards for road construction and the content of digital maps is used for a goal directed segmentation during hypothesis generation. Bordes et al. (1997) perform a database guided road extraction to enhance the vector data accuracy. The underlying road model used for extraction as well as a rough road location is derived from the cartographic database. Wallace et al. (2001) use context information for additional knowledge for linear feature extraction. Within an object-oriented database model different methods for extraction are categorized based on the functionality they provide, which enables the automatic process to choose the best one for a given application. Liedtke et al. (2001) present a system for knowledge-based image interpretation which models structural dependencies by semantic networks. The system is designed to use holistic methods for feature primitive extraction attached to nodes of the network on different semantic levels.

In Walter (1999) automatic feature extraction is applied to quality control and updating of area and line objects in ATKIS by automatically extracting land cover classes by multispectral classification from satellite imagery and comparing it to the corresponding ATKIS objects. Knowledge is derived from the existing GIS for defining training sets for a supervised classification. ATKIS objects that show large differences to the extracted objects with a high probability are presumed to have changed. They are visualized for further interactive analysis by the operator.

The comparison between different data sets is e.g. treated for area objects in Ragia (2000), for linear objects in Wiedemann et al. (1998) and in Straub and Wiedemann (2000).

2. SYSTEM COMPONENTS

The main idea of our developments is to check the quality of the ATKIS DLMBasis by extracting features from black and white orthophotos and comparing the extracted information to the DLM. To increase the efficiency of the quality control, extraction and comparison should be performed fully automatically.

2.1 System Overview

The system is designed to combine fully-automatic analysis with interactive post-processing by a human operator. The fully automatic part attains to reduce the time consuming interaction by a human operator by focussing the interaction on those automatically derived results which are uncertain and unstable.

The system development is embedded in a broader concept of a knowledge-based workstation. Corresponding to the nature of tasks to be solved the system provides functionality from photogrammetry, GIS, and cartography for the acquisition and maintenance of geoinformation. A major goal of this concept is to integrate diverse components performing different subtasks within the framework of a knowledge based system.

Although we presently are focussing on roads the system is designed to handle all object types of ATKIS.

2.2 System Components

The system consists of three major parts: a. the GIS component, b. the process control component and c. the image analysis component (cf. Fig. 1):

The GIS component: The GIS component of the system is based on the GIS ArcInfo 8 and runs with the desktop version under

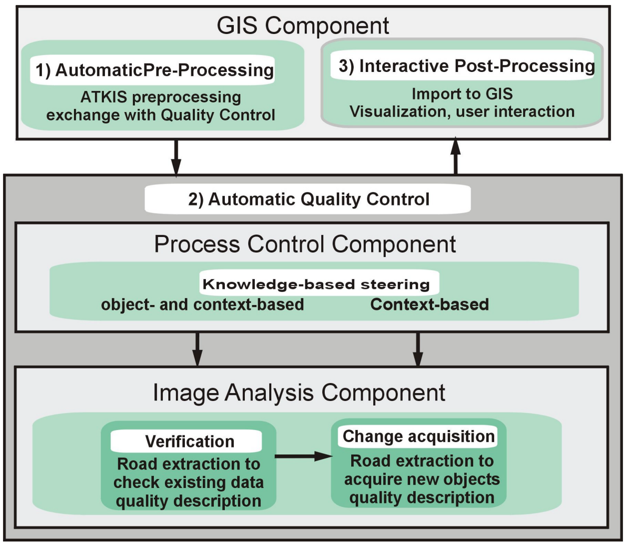

Figure 1: shows the components of the system for quality control

Windows. It is used for automatic pre-processing of the ATKIS data, as an interface to the database and to the image processing system and for interactive post-processing of the automatically derived results. Generally speaking it is the user interface being the workspace for the human operator.

The image analysis component: The image analysis component comprises the automatic cartographic feature extraction modules adapted for the quality check, the comparison of its result to the original vector data and the evaluation of differences between original and extracted roads with the original data leading to quality measures. These tasks are triggered by the GIS data being a valuable source of additional knowledge. The image analysis component is running under Linux and is regarded as being a black box for the operator delivering a preliminary quality description of the data.

The process control component: This part of the system is the link between the GIS component and the image analysis component (cf. Fig. 1). It is responsible for making pre-knowledge from the GIS available to the image analysis component and to transfer it in a suitable way to the object extraction, the comparison and evaluation algorithms. Additionally it is helpful for steering the complete automatic workflow. As the link to the image analysis component is very close the process control component is also running under Linux.

3. PROCEDURE

The procedure for automated quality control is subdivided into three steps: 1) automatic pre-processing, 2) automatic quality control and 3) interactive post-processing (cf. Fig. 1) .

3.1 Automatic Pre-processing

The procedure starts with automatically pre-processing and preparing the GIS data so that it is appropriate for the automatic processes as well as for the interactive analysis by the operator. This pre-processing is performed by the GIS component and compounds e.g. the selection of test area for quality control, the establishment of the link between object geometry and thematic attributes and the supply of an appropriate interface to automatic quality control. Due to practical reasons the working units are image tiles of a certain size, e.g. 2 km × 2 km, or selected image areas which are interactively defined as input to the quality control. For each tile all types of ATKIS objects and their attributes, that are relevant for quality control are requested from the database and are transferred to the image analysis component. At present these ATKIS objects are exported to interchange formats, that can be read by the process control component. In future the transfer will be performed by database queries. The operator simply has to initiate the pre-processing step which then is running in batch.

3.2 Automatic quality control

The second step being the core of the system is the automatic quality control which is performed by the process control component and the image analysis component. The quality control starts with deriving knowledge from the GIS for steering the different steps in image analysis. This especially comprises the selection and sequence of algorithms to be executed and the definition of parameter settings for each. The procedure for automatic quality control is described in detail in chapter 4.

At present the knowledge used for process control is coded in rules which are activated by the geodata. The rules presently describe the knowledge which is required for handling roads and the applied object extraction algorithm. In general these rules can be extended to further object classes and additional algorithms. In future the knowledge will be implemented in a more general way in the knowledge based system presented in Liedtke et al (2001) which is to be advanced for quality control purposes within our cooperation with the Institut für Theoretische Nachrichtentechnik und Informationsverarbeitung, Hannover University.

The automatic quality control is carried out as a batch process started via the GIS component. The result of the feature extraction steps as well as the quality description of the ATKIS objects are stored in exchange files and are delivered back to the GIS component, where the operator performs the post-editing of those parts of the scene description, which could not be reliably analysed by the automatic process.

3.3 Interactive Post-processing

During the final interactive check of the results the operator focuses on roads for which the automatic quality control indicated an uncertain decision. If necessary the operator has to revise and correct the automatically derived quality description. To ensure that all objects will be handled that are classified as being uncertain, the user can be guided by sequentially presenting him all objects stored in a queue.

For supporting the operator during his interactive intervention the automatically derived quality measures and the underlying extraction results are visualised in an appropriate way together with the orthophotos on the screen. The graphical user interface (GUI) for user intervention provides the following functionalities:

- access to the ATKIS objects and their attributes
- access to the results of the automatic quality contol
- tools for the final editing by the human operator
- tools for documentation of the results

It allows the operator to correct or complete the results of the automatic procedure and to classify errors into different error classes like missing objects, inaccurate object geometries and wrong attributes. For further details we refer to Busch and Willrich (2002).

4. AUTOMATIC QUALITY CONTROL

In the following we describe the fully-automatic part in detail. It is to be regarded as being a black box for the human operator delivering a preliminary quality check for focussing the interactive intervention.

The quality control comprises road extraction adapted for the quality check, the comparison of its result to the original vector data and the evaluation of differences between original and extracted roads with the original data leading to quality measures.

4.1 Algorithms for Road Extraction

International research has produced many different algorithms for road extraction each of them being suitable for well-defined extraction tasks. Our concept for checking the quality of roads in general is designed to use different algorithms for road extraction. The selection of the appropriate algorithm in each case is performed by the process control component. We currently apply software developed by C. Wiedemann (cf. Wiedemann et al. 1998, Wiedemann 2001) at the Chair for Photogrammetry and Remote Sensing at the Technical University Munich. We adapted it to our specific tasks especially by exploiting the GIS scene description and embedded it into the knowledge-based framework for deriving a quality description of each handled road object. The underlying road model thereby is partly adapted by parameter settings which are automatically defined or even adapted to the image content by the process control component.

4.2 The use of pre-knowledge for quality control

The knowledge we use for road extraction and for describing the quality of roads is derived from object-specific and context-specific properties whereas the context can be subdivided into global and local context (cf. Baumgartner et al. 1997):

Object-specific properties are e.g. the road geometry as well as road attributes like the road type (highway, single/multi track, road, path), road width, road material (asphalt, concrete). These properties usually are partially represented in the underlying road model of each algorithm and thus characterize the application domain of the algorithm. In many algorithms they can be adapted to the scene by parameter settings. The applied road extraction software e.g. has a parameter describing the width of the road to be extracted. In ATKIS the road width is an attribute of road objects and thus for checking the quality of existing roads this parameter can directly be defined by ATKIS. The road geometry of existing roads can further be used to define regions of interest in which the road extraction is performed.

The global context, e.g. the environment through which a linear feature passes influences the appearance of the road in the images e.g. by probabilities for having disturbances like shadow, fragmentation or low contrast. The expected appearance of the road in general is part of the underlying road model of each algorithm and in many cases can be adapted to the scene by parameter setting as it is done in our case. For extraction and evaluation we use three types of context regions derived from the geo-data: rural, urban and forestry. The appropriate parameters settings for each context class were defined by empirical studies and then are coded in rules.

The local context, e.g. the local neighborhood relations between different objects also influences the appearance of the road in the images by interrelationships like occlusion and shadow, connectivity and parallelism conditions (e.g. buildings cast shadows on roads and buildings in general are connected to roads). It is complex to model the influence of local context and therefore we did not considered it in our approach yet.

4.3 Verification and Change Acquisition

The main principle of our procedure for quality control is to exploit the initial scene description in the geo-database to guide and constrain the underlying road extraction and the comparison with the given vector data in the following way:

- by definition of regions of interest
- by selection of the appropriate algorithm
- by parameter control of the road extraction
- by parameter control for evaluating the results

Depending on the different quality aspects to be checked like geometric or thematic accuracy of existing roads on the one hand and completeness of the road data on the other hand we perform the quality control in two stages: 1. the verification of existing roads and 2. the acquisition of changes in the road data. This partitioning mainly is motivated by the different amount of knowledge which can be exploited. In both cases we first perform road extraction and then compare its result to the roads given in ATKIS.

4.3.1 Verification

The verification checks those objects which are described in the database. It is able to check the positional and the thematic accuracy as well as the commission error (road does not exist in reality). Besides very general knowledge about the roads, in this case specific knowledge can be derived for each individual instances of an ATKIS object and can be used for parameter steering during extraction and quality evaluation in the sense of the hypothesis-verify paradigm.

To introduce the specific knowledge given by object instances the verification is performed object by object by comparing the existing road data with roads extracted from the images. The geometric and thematic description of each existing object is transferred to constraints in the road extraction of each object. The geometric description e.g. is used for defining regions of interest, the thematic attributes are used to select the appropriate algorithm and its parameters.

4.3.2 Acquisition of Changes

The acquisition of changes aims at finding objects which are not contained in the database and thus serves for describing the completeness of the data especially by registering roads which are missing in the database. This task being equivalent to object extraction from the scratch is more difficult than the verification task because we only can introduce general knowledge and have to renounce on specific knowledge derived from existing roads. Solely the global context can be derived from ATKIS and can be used for parameter setting of the road extraction algorithm as it also is done during the verification step. The acquisition of changes is executed subsequently to the verification to at least introduce verified ATKIS objects as reliable road parts and use it as seeds during the network generation (cf. Wiedemann 2001).

4.4 Quality evaluation

The first step in both tasks, verification and acquisition of changes, is the extraction of roads. The extracted roads then are to be compared to the given ATKIS roads to derive a quality description of each single road object as well as of the complete road network. Our focus is on describing the quality in terms of correctness, completeness and accuracy (cf. Wiedemann et al. 1998) of the geometric and thematic description of the objects. We do not cope with the consistency of data and model which can be checked by logical tests as it is already performed in many cases in practice.

Respectively to the road verification and change acquisition tasks the quality evaluation also has to distinguish 1) roads in the database and 2) roads that are newly acquired.

4.4.1 Quality description in road verification

To derive a quality description in road verification the differences between the extracted roads and the GIS data are analysed and evaluated. The quality description is simplified to a so-called traffic-light solution (cf. Fig. 2) indicating three types of quality attributes: *accepted, rejected, undecided*.

We first check if an extracted road matches the corresponding ATKIS object. If the road extraction has been successful the road is denoted *accepted*. If no road matches the ATKIS object the local situation is to be further analysed in a second step by a feedback loop to determine if the error was caused by inaccurate attributes, inaccurate geometry, by application of a unsuitable road model, by difficult contrast conditions or by the road having ceased to exist. We first go back to the underlying line extraction being the basis for extracting roads and test how good these lines fit the ATKIS road. We especially check the coverage of lines which fit the direction and position of the

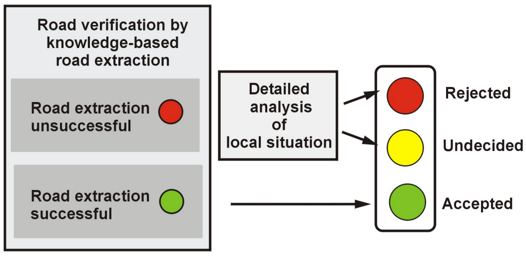

Figure 2: shows the classification of ATKIS roads into the three quality classes *accepted*, *rejected* and *undecided*.

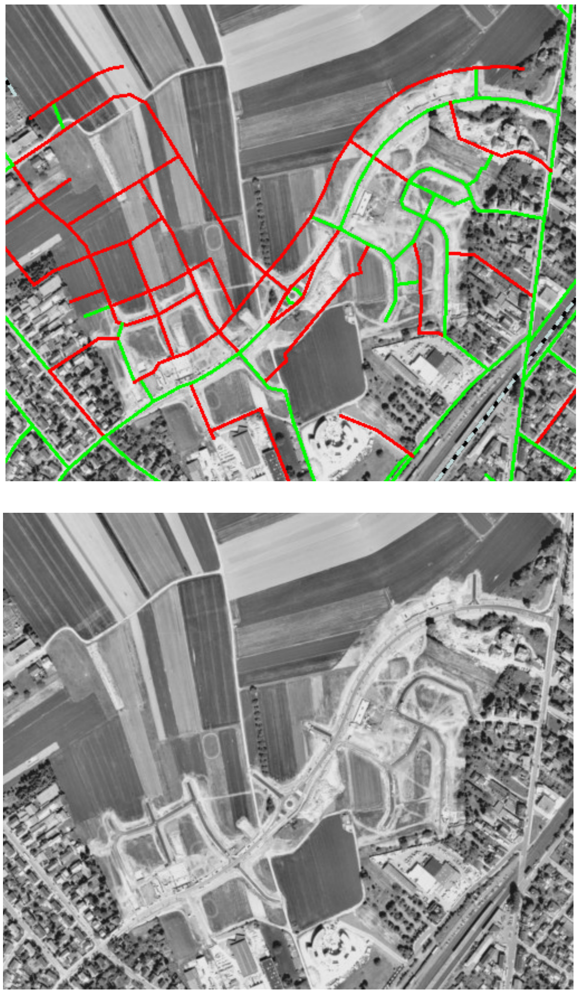

Figure 3: shows an example of the verification result for an updating situation where the geo-data differ from the image content due to road construction. Please note that in this example the imagery is older than the ATKIS data and thus the imagery does not reflect all new roads which already are contained in ATKIS (accepted roads in green, rejected roads in red) (ATKIS®, DLMBasis und Orthophotos; Copyright © Hessisches Landesvermessungsamt 2002).

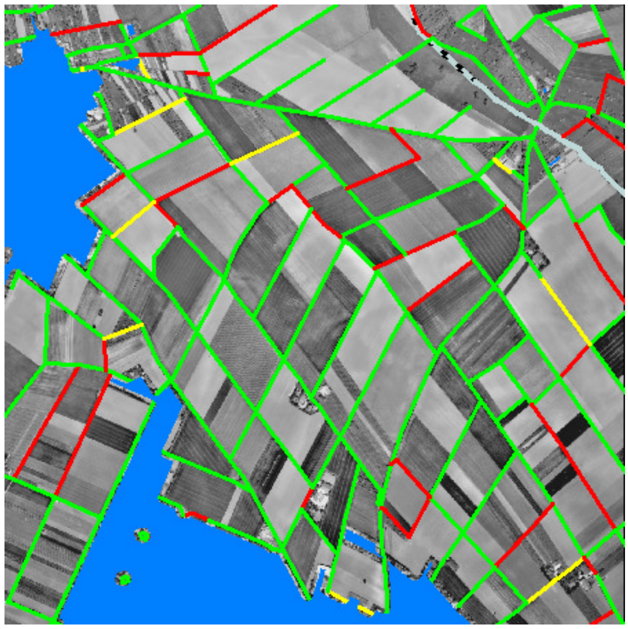

Figure 4: shows an example of the verification result in rural context represented by a classification of the ATKIS roads into the three quality classes *accepted, rejected* and *undecided* as it is transferred to the interactive post-editing. Green lines denote accepted, red lines rejected and yellow lines undecided roads. (ATKIS®, DLMBasis und Orthophotos; Copyright © Hessisches Landesvermessungsamt 2002)

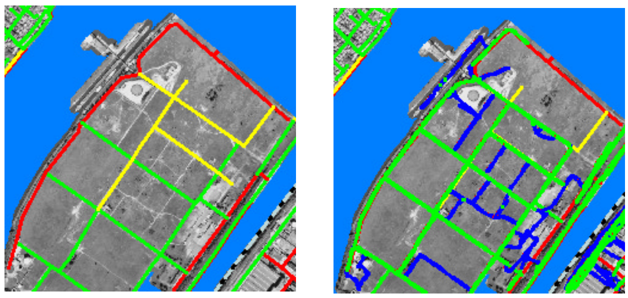

Figure 5: shows the result of the automatic verification (left) and the change acquisition result (blue lines) overlaid over the verification result (right).

ATKIS road. If the coverage[1] c is larger than a threshold (in our cases set to 60%) the road is denoted as *undecided.* If c is less than this threshold we propose to go to the pixel level to test the local contrast by analysing grey value profiles perpendicular to the road axes. This could give hints to wrong geometry, or to contrast situations which actually can not be handled by the currently employed road model like an unsymmetric line model. Depending on the situations the ATKIS road to be inspected is denoted as *rejected* or in case of the unsuited road model denoted as *undecided.* The quality classes *undecided* is to be

[1] $c = \frac{l_{ml}}{l_a}$ with l_{ml} = length of matched lines and l_a = length of ATKIS road

presented to the operator. Fig. 3 and 4 show examples of the automatically derived quality description in road verification.

4.4.2 Quality description in acquisition of changes

In acquisition of changes we are interested in new objects which are not contained in the original dataset. They are derived by subjecting the roads extracted in the complete image to the evaluation scheme proposed by (Wiedemann et al. 1998) by matching the extracted roads to the existing roads in the database and vice versa. Unmatched extractions are denoted as changes and are delivered to the operator. Fig. 5 shows an example of automatically derived changes. As there still are many extracted road elements being wrong interpretations a further classification of these changes is required, e.g. by deriving their internal accuracy using the underlying line extraction to obtain a reliability measure of the changes. The reliability of the road extraction result especially depends on the extraction context and on the underlying low-level extraction used for road network generation. It could be used to derive a traffic-light-solution describing the quality of the data by a qualitative description as it is done during the verification of the existing data. Thus the user interaction can further be reduced to very probable changes.

5. RESULTS AND DISCUSSION

For evaluating the performance of our procedure we tested the verification step with 30 orthophotos covering an area of *10 km x 12 km* near Frankfurt a.M. The black and white images meet the ATKIS orthophoto standards with *0.42 m* resolution on ground. The complete scene is subdivided into three classes of context areas. The 10368 roads in the covered scene roughly split into 43% in rural, 42% in urban and 13% in forestry context. The used road extraction software (cf. chapter 4.1) is designed to provide optimal results for resolutions between *1–2 m* on ground in rural context. Therefore we resampled the given imagery to *1.70 m*. The road data we checked are part of the ATKIS DLMBasis. Compared to the imagery these vector data are nearly up-to-date.

Table 1 shows the achieved verification results of the existing roads subdivided into three context classes rural, urban and forestry. The classes are automatically derived from the given ATKIS objects of type region by grouping those ATKIS regions showing similar appearance in the images. For each class we used empirically determined optimal parameter settings. The table shows the number of roads being either *accepted, rejected* or *undecided* in % of all roads covered by the context area. In rural context the percentage of accepted roads is about 79 %, the percentage of rejected roads were 17 % whereas in 4 % of the roads an uncertain decision of the automatic system was derived. The optimum of accepted roads is estimated to be approximately 95 % as the scene is nearly up-to-date and only some roads especially being tracks are even uncertainly arbitrable by a human specialist.

The reasons for rejecting roads in rural context is mostly caused by applying an unsuitable road model for extraction in local contrast conditions changing from dark to light neighbourhood or vice versa or by roads showing very low contrast to its surroundings. Therefore we propose to further inspect rejected roads by analysis on the pixel level e.g. by analysing grey values of cross sections along the road axis to obtain hints for the reason of rejecting the road which e.g. can be used to select a more suitable road model. The results in urban context only reach a percentage of accepted roads of 57% while 34% were rejected and 8% were undecided roads. The reason for the worse results is that parameter settings had to be set differently to prevent a large number of false positives.

We tested for false positives both in rural and in urban context by shifting the ATKIS data set relatively to the imagery *30 m* in **x** and *30 m* in **y** direction. The results are given in Table 2. The optimal result should be 0 % of roads to be accepted. The results show in rural area a false positive rate of 33% and in urban area of 21%. In fact in rural area these numbers are a little too large because for some roads the shift results in a change in road direction still effecting a large overlap with the original road (cf. Fig. 6). Therefore some roads by mistake are assigned to the class *accepted*. Further false positives are caused by roads running through textured context area like e.g. specialised cultivation in rural area or low contrast area. In future we therefore propose to handle specialised cultivation area as an additional context area with different parameter settings.

Context region	*% accepted*	*% rejected*	*% undecided*
rural	79	17	4
urban	57	34	8
forestry	60	34	6

Table 1: shows the achieved verification result subdivided into three context classes by the number of roads in % of all roads covered by the context area in the image being either *accepted, rejected* or *undecided*.

Context region	*% accepted*	*% rejected*	*% undecided*
rural	33	64	3
urban	21	75	4
forestry	18	81	1

Table 2: shows the achieved results with ATKIS shifted relatively to the imagery.

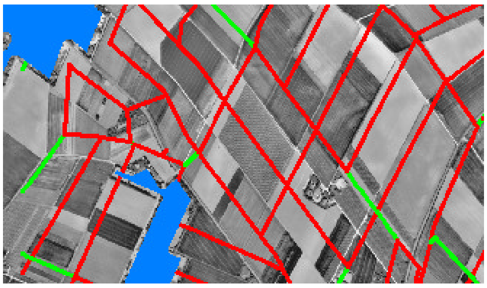

Figure 6: shows an example of the verification where the given ATKIS roads are shifted (accepted roads in green, rejected roads in red)

The results in forestry area are not very satisfying but are plausible as many of the roads even could not be verified by a human operator based on the imagery. Only very wide roads like e.g. highways could be automatically verified in this context area. For verification in urban as well as in forestry area different sensors like e.g. laser scanning data have to be used additionally to the imagery. Thus the 3d information can supplement the 2d information to preclude buildings and trees.

6. CONCLUSIONS AND OUTLOOK

We presented our procedure for automated quality control of the Authoritative Topographic-Cartographic Information System ATKIS in Germany for checking the consistency of the data with reality represented by imagery. To solve this task in an economical way the procedure comprises a fully automatic part which is followed by interactive correction by a human operator. The fully automatic part reduces the subsequent user interaction by focussing on those objects where the results of the automatic process are uncertain and therefore a user interaction is required to reach a reliable results. First results show the feasibility the concept. The verification has to be refined by integrating alternative algorithms for road extraction, by further feed-back during the quality evaluation and by reducing the rate of false positive alarms. The results in change detection have to be refined by evaluating the initially deduced changes and have to be tested on a large test data set to rate its performance.

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