SYSTEM DESIGN FOR AUTOMATED QUALITY CONTROL OF GEODATA BY INTEGRATION OF GIS AND 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 area-wide available topographic vector data set ATKIS® in Germany using images. To reach an efficient solution our concept is designed as an automated system, which comprises automatic cartographic feature extraction and comparison with ATKIS. By integration of image analysis and GIS both tasks are triggered by additional knowledge derived from the existing scene description. Our concept admits user interaction to perform a final check of the fully automatically derived quality description of the data to reach an operational solution.

1. INTRODUCTION

A quality description of geodata in a database is required for many applications because tasks like environmental planning, documentation and analysis highly depend on the quality of the input data used for it. Thus, quality control should be the first step in data processing, data analysis, maintenance or homogenisation of different data sets to ensure a well-defined result in any of these processing tasks.

For checking the quality of existing geodata and for updating the data an efficient procedure for quality control is required covering on the one hand the consistency of the data with the data model and on the other hand the consistency of the data with reality. Efficiency can be reached by an automated or even fully automatic approach. In many applications the first aspect is successfully performed in an operational way. The second aspect, the consistency of data and reality still is an active research field. One possible approach for solving this task efficiently is by automatically comparing the geodata to digital imagery which highly needs for an integrated solution combining image analysis and GIS.

Image analysis especially includes automatic feature extraction from imagery to derive an image description which can be compared to the geodata. Experiences in automatic cartographic feature extraction (e.g. Baltsavias et al. 2001) have shown that algorithms particularly give good results if applied to well-defined application areas. The reason is that all approaches need additional knowledge to be involved by using appropriate models, which can more easily be formulated for restricted situations.

GIS data in general can provide a valuable source of additional knowledge (cf. Vosselman 1996) and can be used to stabilize the image interpretation tasks. Examples are given in e.g. Quint and Sties (1995), DeGunst and Vosselman (1997), Bordes et al. (1997), Walter (1999) or Wallace et al. (2001). Knowledge based systems have proven to be a suitable framework for representing knowledge about the objects and exploiting it during the recognition process. Liedtke et al. (2001) present a system for knowledge-based image interpretation for land use interpretation which models structural dependencies by semantic networks. The system is designed to use holistic methods for feature primitive extraction attached to nodes on different semantic levels.

In contrast to cartographic feature extraction from scratch the starting position for quality control of existing data is different, as an initial scene description already is available. In this case algorithms for object extraction as well as the comparison of the extracted features with the geodata to derive a quality description can benefit from the information contained in the GIS. Both steps however require a close and well-defined interaction between image analysis and GIS.

A major task of the Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG) consists in providing the geodata of the Authoritative Topographic-Cartographic Information System ATKIS®, a trademark of the Working Committee of the Surveying Authorities of the States of the Federal Republic of Germany (AdV), on the territory of the Federal Republic of Germany. Components of ATKIS are object-based digital landscape models (DLM) encompassing several resolutions, digital topographic maps (DTK) in vector and raster formats and standardised orthophotos (DOP). The ATKIS DLMBasis, i.e. the ATKIS data of the highest resolution, are produced by the 16 surveying authorities of the federal states of Germany and are delivered to the BKG, where they are stored in a database at the Geodata Centre (GDC) of the BKG (Endrullis 2000). Since these data are delivered to customers on the one hand and are used to derive data of smaller scales within the BKG on the other hand, a system for quality control of the ATKIS data is essential.

This paper presents the concept of quality control of the ATKIS DLMBasis as it is proposed at the BKG. Parts of it already are performed in an operational way within the daily production process. To solve the complete process chain in an efficient way BKG has initiated a common project with the University of Hannover to develop a system for automated quality control of ATKIS DLMBasis using digital orthoimages.

2. QUALITY OF GEODATA

2.1 Quality Measures

Data quality should be rated by a certain set of measures, which give us expressive, comprehensive and useful criteria. They should enable the user to compare the quality of different data sets. Therefore quality measures are part of standards or specifications from e.g. ISO, CEN, or the OpenGIS Consortium. We do not want to go into detail on these specifications but start with a subdivision of quality measures into two categories that are important for practical applications owing to the arguments given below:

1. Quality measures that concern consistency with the data model (LOGICAL CONSISTENCY),
2. Quality measures that concern consistency of data and reality within the scope of the model (REAL WORLD CONSISTENCY).

Within the scope of this paper we call the first category logical consistency since it is characterized by the fact that it can be checked without any comparison of the data and the real world. Hence, we can perform a complete check of this category using solely the data set without additional information. Only routines and functionality within the database or the GIS are needed. Once implemented, the inspection of logical consistency can be performed automatically. Examples for logical consistency are format specifications, topological constraints, uniqueness of identifiers, and attribute values within their correct ranges.

The second category requires a comparison of data and reality. In this paper we refer to it as real world consistency, too. In principal, the comparison can be performed by means of current sensor data or field work. A complete comparison of data and reality requires a lot of effort and cost, but it furnishes all the update information for the data.

A well defined system of four quality measures is given by Joos (2000). His criteria, namely completeness, correctness, consistency, and accuracy, are conceptually independent or orthogonal. Consistency in the sense of Joos is part of logical consistency as defined in this section. Some aspects of completeness cover logical consistency, too, e.g. attribute completeness which concerns the question whether all required attributes are stored together with an object. Most aspects of completeness, correctness, and accuracy must be checked in comparison to reality. It has to be verified, whether e.g. all objects are registered in the data set and whether their attributes are set correctly. Accuracy concerns positional accuracy and temporal accuracy, i.e. currency.

2.2 Quality Management of ATKIS at the BKG

One major task of the BKG consists in joining the ATKIS DLMBasis delivered by the federal states to one homogeneous data set for providing ATKIS on the territory of the Federal Republic of Germany. This includes establishing logical and geometrical consistency at the borders of the different data sets from the surveying authorities by quality control. Automatic routines that test logical consistency of the data sets with the model have been implemented at the Geodata Centre (GDC) which perform an exhaustive check on the full coverage of the data. Thus, the check of logical consistency is done in an operational way within the daily production process requiring computation power and computation time only.

In practice the comparison of the ATKIS data to the real world still is far away from being fully automatic. At BKG the comparison is implemented as an interactive procedure based on the GIS software ArcInfo 8 and is performed for sample areas having a size of about 10 km × 10 km. A human operator compares the data of the ATKIS DLMBasis with orthoimages of recent date which are an up-to-date reference of reality and can be used to assess completeness, correctness, positional and temporal accuracy. Our main interest concerns frequently changing and important objects, namely the road network and built-up area. Other objects and their attributes can be verified, too, if they are visible within the images.

Currently we are automating the interactive quality control step by step using procedures that have been developed in the research and development project with the University of Hannover. The automated procedures consist of automatic steps that are started by an operator and give back a result that requires further interaction of the operator.

Any error that is detected during the quality control is reported to the respective federal state. Since the federal states are producers of the data of the ATKIS DLMBasis, they are responsible for the appropriate amendment of the data. When the errors have been corrected, the updated datasets from the surveying authorities of the federal states are delivered to the BKG again where they are stored in the database at the GDC. This procedure guarantees that there exists only one exclusive and unique dataset of the ATKIS DLMBasis.

3. SYSTEM DESIGN

In the following we describe our system development for checking the quality of the ATKIS DLMBasis in the sense of real world consistency.

3.1 Strategy for Quality Control

The real world consistency is checked by extracting features from black and white orthoimages and comparing the extracted information to the DLM. To increase the efficiency of the quality control, extraction and comparison should be performed fully automatically as far as possible.

The system concept combines fully-automatic analysis with interactive post-processing by an operator whereas the fully automatic part reduces the amount of time consuming interaction by an operator by focussing the interaction on uncertain results. We admit the final user interaction to reach a high reliability of the final result which however is needed for operational systems but at present can not be reached by fully automatic procedures (cf. Lang and Förstner 1996).

The prototype for automated quality control is designed to be a knowledge-based system. Additional knowledge is used to stabilize the automatic analysis by reducing the geometric search space and the possible scene interpretations. The knowledge we use is partially derived from the existing geodata (here ATKIS) and is coded in rules. In future it will be implemented in the knowledge-based system presented in Liedtke et al. (2001). Although in general the system is designed to handle all object types of ATKIS we presently are focussing on those objects for which highest currency is required, i.e. we test it on roads.

3.2 System Components

The system development is embedded in a broader concept of a knowledge-based workstation. The major goal of this concept is to integrate several components performing different tasks like knowledge-based photogrammetric image analysis, cartography and GIS for the production of geoinformation, especially for the acquisition and maintenance of geoinformation. Therefore the system consists of three major parts: a. the GIS component, b. the photogrammetric component and c. the knowledge-based component with well-defined interaction between each of them:

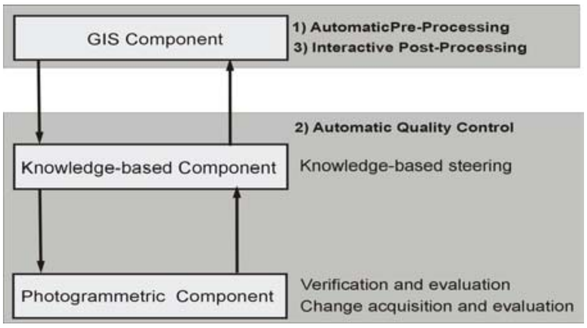

Figure 1. The components of the system for quality control

The GIS component: The GIS component of the system is based on the GIS ArcInfo. It is used for automatic pre-processing of the ATKIS data, as an interface to the database and to the image processing system, for interactive post-processing of automatically derived results and generally spoken as user interface and for the overlay of aerial images and ATKIS data.

The photogrammetric component: The photogrammetric component comprises the automatic cartographic feature extraction modules and the comparison with the original vector data leading to quality measures. Both tasks are triggered by the GIS data being a valuable source of additional knowledge. The results are transferred to the GIS component and are used to support the operator during the interactive final check and during geometric corrections.

The knowledge-based component: This part of the system is responsible for making pre-knowledge from the GIS available and transfer it in a suitable way to the photogrammetric component, that is to the object extraction, comparison and evaluation algorithms. Additionally it is helpful for steering the complete automatic workflow.

4. AUTOMATIC QUALITY CONTROL

The workflow for automated quality control, checking the consistency of data and reality is subdivided into two automatic steps: 1) automatic pre-processing of the geodata, 2) automatic quality control. The automatic procedure is followed by interactive quality control, where the operator checks those automatically derived results, which are denoted by the automatic steps as being insecure.

In the following we describe the automatic part in detail. It is to be regarded as being a black box for the operator delivering a preliminary quality check for focussing the interactive intervention (cf. chapter 5) by the user.

4.1 Pre-processing of the Geodata

The procedure starts with automatically pre-processing and preparing the GIS data so that it is appropriate as well for the automatic processes as for the interactive analysis by the operator (cf. chapter 5). This pre-processing is performed by the GIS component and compounds e.g. the selecting the area to be checked, establishing the link between object geometry and thematic attributes and supplying an appropriate interface to the knowledge-based and the photogrammetric component. Due to practical reasons the working units are image tiles of a size of e.g. 2 km × 2 km or interactively selected image areas defined for 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 photogrammetric component. At present these ATKIS objects are exported to interchange formats, which in future the knowledge-based photogrammetric component but in future this transfer can read will be performed by database queries.

4.2 Automatic Quality Control

The automatic quality control is carried out by the knowledge-based and the photogrammetric component. It comprises GIS-driven automatic road extraction adapted for the quality check and the comparison of its result to the original data. The results is given by a quality description which is delivered to the GIS component, where the operator performs the well directed pre-editing of those parts of the scene description, which could not be reliably analysed by the automatic process (cf. chapter 5).

GIS-driven Automatic Road Extraction: For road extraction in quality control our concept in general is designed to use different algorithms whereas the selection of the appropriate algorithm is performed by the knowledge-based component. At present we 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 steering and deriving quality statements.

The automatic steering of the road extraction procedure is done by automatically adapting the algorithms to the local situation predefined in the GIS. This adaptation is performed by the knowledge-based component. The knowledge we use distinguishes object-specific and context-specific properties which usually are partially represented in the underlying road model of each extraction algorithm and thus characterize the application domain of the algorithm. Therefore we adapt the underlying road model to the expected image content given by the existing scene description like it is defined in ATKIS. Object-specific properties e.g. are the road type (highway, single/multi track, road, path), road widths or road constitution (asphalt, concrete). Context-specific properties we use are defined by the global context. E.g. the environment through which a linear feature passes or is contained in influences the appearance of the road in the images e.g. by probabilities for having disturbances like shadow, fragmentation or low contrast and is also part of the underlying road model. At present we use three types of context regions given by the GIS for extraction and evaluation: rural, forestry and urban. The appropriate parameters of the corresponding road models are defined by empirical studies.

Depending on the pre-knowledge which can be used for steering the road extraction during the quality control we distinguish two different functionalities in quality control: a) the verification of existing roads and b) the acquisition of changes in the road data. The partitioning mainly is motivated by the different amount of knowledge, which can be exploited during road extraction and the subsequent evaluation of the differences.

a) *Road Extraction for Verification:* The verification focuses on those objects, which are described in the database and checks the positional and the thematic accuracy. Concerning the completeness of the roads wrong road elements can be revealed but missing roads can not be detected. Beneath general context information object specific knowledge defined by the object instances in the database is used during the road extraction. Therefore the verification is performed object by object. Within the knowledge-based component the geometric and thematic description of each object instance in the road database is transferred to constraints for defining regions of interest, the appropriate algorithm and its parameters which are used for automatic road extraction for verification of the respective ATKIS object.

b) *Road Extraction for Acquisition of Changes:* The acquisition of changes especially aims at registering missing roads in the road database to derive the quality aspect completeness. In this case we can only use very general knowledge about the scene, about the global context and in general about the objects of interest. In contrast to road verification no object-specific knowledge can be introduced as no object instances are available. Therefore the acquisition of changes is even more difficult and can be compared to object extraction from scratch, where no constraints are given by the GIS. It is executed subsequently to the verification to introduce verified ATKIS objects as reliable pre-information e.g. in the road network generation (cf. Wiedemann et al. 1998) in our further developments.

4.2.1 Quality Evaluation

Following the road extraction either for verification or for change acquisition, the extraction result has to be compared to the existing geodata to derive a quality measure. In both cases the quality description is simplified to a so-called traffic-light solution indicating three types of quality attributes: verified, rejected, and undecided (cf. fig. 2). The quality measure also has to distinguish road verification and acquisition.

Quality description in road verification: For verification we check if and how good an extracted road matches the corresponding road object in the database. If the database object could be extracted, it is denoted as verified. For road elements which could not be initially verified the reason for an unsuccessful road extraction is analysed by refined verification in a feed-back-loop following the hypotheses and verify paradigm. The generation of new hypotheses is performed by analysing the local geometric and radiometric situation in the raster data. E.g. the extracted lines being an intermediate step in road extraction and the original data are analysed with regard to their geometric deviation and their coverage with the database object. The analysis within the feedback-loop finally results in a quality description distinguishing undecided or rejected and could be used for classifying the error type into attribute error or error in geometry.

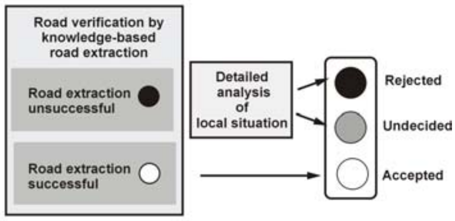

Figure 2. shows the classification of ATKIS roads into the three quality classes accepted (white), rejected (black) and undecided (grey).

Quality description in acquisition of changes: In acquisition of changes we compare the extracted roads to the verified roads in the database using the evaluation scheme proposed by (Wiedemann et al. 1998). This comparison leads to new road objects which are not contained in the database and probably can be denoted as changes. At present they are directly delivered to the operator for a final interactive check. Thus the user interaction is focussed to probable changes. As there still are extracted false road elements a refined quality description of these changes is required, which e.g. could be derived using the internal accuracy of the extracted roads.

The underlying result of the feature extraction steps as well as the automatically derived quality of the ATKIS objects are stored in exchange files. They are transferred back to the GIS component and are used to support the operator during the interactive final check and during geometric corrections.

5. INTERACTIVE QUALITY CONTROL

5.1 Workflow

The data of the ATKIS DLMBasis are stored in the GeoDataCenter at the BKG. From this database we fetch all objects that intersect the area covered by the orthoimages and that usually are visible in digital imagery. They are visualized together with the imagery using ArcMap. By means of a uniform legend and an appropriate order of the ATKIS objects on the screen we avoid that certain objects hide each other. If the operator realizes an error that concerns an existing ATKIS object, this object is copied to a special layer. The type of detected error is selected easily from a list of possible errors that are displayed in a box on a click of a mouse button. Missing objects are added to the same layer using the editing functionality of ArcMap. The object type for the missing object and other attributes are appended on mouse click from a predefined list. There is no functionality to assign topological relations with other ATKIS objects or to build up a complete topology. This it not necessary since the results are reported to the responsible authority, i.e. the federal state that produced the dataset. For this purpose it is sufficient to provide the information needed to locate and identify the errors. All errors that have been recorded by this procedure can be exported to any format supported by ArcInfo.

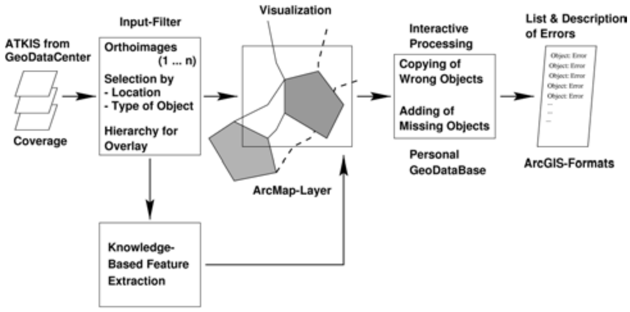

Figure 3. Workflow of quality control

5.2 Integration of Automated Feature Extraction

An efficient interlocking of the interactive steps of the operator and the automatic verification procedure as described in Section 4 is essential to guarantee an optimal workflow and a significant increase in productivity. Therefore the operator needs a graphical user interface (GUI) that allows fast and simple access to

- the image data,
- the relevant data from the ATKIS DLMBasis,
- the automatic verification procedure from Section 4,
- the tools to convert the ATKIS data to formats that can be read by the automatic verification procedure,
- the results of the automatic verification procedure,
- the tools for the final editing of the results.

After the automatic verification procedure has run as a batch process in background or on a separate server, the results are available for the interactive post-processing. The quality measures are delivered as attributes of each inspected ATKIS object. They are used for a functional visualization to guide the operator to those objects that require his intervention. Of most importance are situations where the knowledge-based system indicates an uncertain decision. In these cases the final decision is made by the operator who classifies it as verified or not verified. All ATKIS objects that could not be verified by the automatic verification procedure have to be checked by the operator, too. Here the decision of the system has to be corrected, if necessary. To ensure that all objects that are classified as uncertain or not verified are processed, they can be stored in a queue that has to be worked of. Figure 3 shows the workflow of the interactive quality control process. It demonstrates that pre-processing and input filtering are identical for the automated and the purely interactive procedure.

6. RESULTS

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 am Main. The black and white images meet the ATKIS orthophoto standards with 0.42 m resolution on ground and the used road extraction software resampled it to 1.70 m. 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 achieved verification results of the existing roads are subdivided by the 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. 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 undecided 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 their 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 can be used to select a more suitable road model. The results in urban and forestry context (accepted roads about 60%) are worse than in rural area as the applied road model is not suitable. For further details we refer to (Willrich 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. White lines denote accepted, black lines rejected and dashed lines undecided roads. (ATKIS®, DLMBasis und Orthophotos; Copyright © Hessisches Landesvermessungsamt 2002)

Figure 5 shows an example of the verification result for an updating situation where the geodata 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.

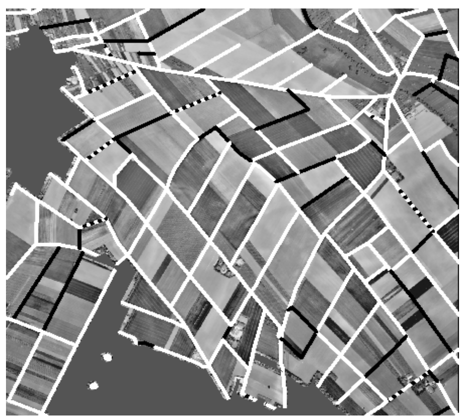

Figure 4. verification result in rural context (accepted (white), rejected (black) and undecided (dashed)).

Figure 5. verification result for an updating situation due to road construction (ATKIS is up-to-date but not the imagery)

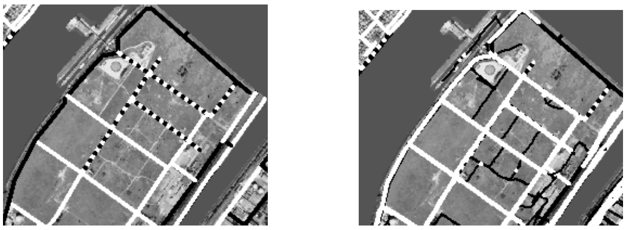

Figure 6. automatic verification result (left) and change acquisition result (thin black lines) overlaid over the verification result (right).

7. CONCLUSIONS

This paper presented our system for automated quality control of geodata. For checking the consistency of the data with reality our concept provides an integration of GIS and image analysis using a knowledge-based approach. To solve this task in an economical way we presented a prototype of a knowledge-based photogrammetric cartographic system, which we developed to speed up the whole production workflow in quality control. The system is designed to increase the efficiency of the updating process by combining automatic procedures with user interaction in a GIS environment. First results with a large test area demonstrate the range of our concept.

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