AUTOMATIC QUALITY SURVEILLANCE OF GIS DATA WITH GEOAIDA

S. Müller, M. Weis, C.-E. Liedtke and M. Pahl

Institut für Theoretische Nachrichtentechnik
und Informationsverarbeitung
University of Hannover, Germany
geoaida@tnt.uni-hannover.de

KEY WORDS: Quality Control, GIS, Semantic Net, Knowledge Based Image Interpretation, Sensor Fusion

ABSTRACT

Digital spatial data are subject to temporal changes. The common approach to verify and update the data is to superimpose the data with up-to-date orthophotos and check the correctness interactively. This is a very time consuming and expensive process. We propose a method for the automatic quality surveillance of GIS data, in particular in respect to changes of settlement and industrial areas. These classes correspond to the classes defined for the German ATKIS® geodata. In this paper the up-to-dateness of ATKIS is checked by use of a high resolution color aerial image of a scene near Hannover. The analysis uses the knowledge-based system GEOAIDA, which allows an intelligent, clearly structured, and flexible control of a scene interpretation by utilizing a semantic scene description. GEOAIDA is extended to use a state transition graph that models possible expected temporal transitions in the scene. The system produces a hierarchic, pictorial description of the results while the structural context of the identified objects including the associated attributes is preserved in a graph. The results of a quality surveillance procedure in the examined GIS data are illustrated.

1 INTRODUCTION

Quality of geodata refers to the geometric and semantic correctness as well as on the up-to-dateness. Most effort is concentrated on keeping up with the changes in the area described by the data. In Germany the update period of ATKIS, which is a reference frame of topographical information used for the integration of specialized geodata, is about five years. Methods to validate the information stored in a geo-database are to compare the data to the most recent information sources available like aerial images or planning data. Our aim is to support the interactive comparison by generating a complete interpretation of the scene in the aerial image and by drawing the attention to conflicting situations. The aims are twofold: one, the automatic interpretation of complex scenes and two, the automation of quality control.

The geodata which is to be verified is the German ATKIS (Authoritative Topographic-Cartographic Information System for Germany). It provides the governmental topographical data for the whole country. The generation of the data is the task of 16 German surveying authorities. The underlying data model defines the objects and types of attributes which have to be acquired for the Digital Landscape Model (DLM). The acquisition is obtained using different data sources and therefore can be of slightly differencing quality. Different methods exist to automatically check the quality of data, particularly the inner consistency with the data model as defined in the objects catalogue (AdV-Arbeitsgruppe ATKIS, 2002). Other quality aspects include checking the conformity between data and the situation in the reality (Busch and Willrich, 2002). This is the task of the developed system, and the data source used as portrayal of the reality are aerial images. These images are produced in standardised intervals and quality and are considered as reliable, up-to-date and a complete data source. The raster images are regarded as an independent data source and therefore can be used for the comparison. The goal is to develop an automatic system which is able to generate an interpretation of the raster data on a high level of object abstraction and to compare this interpretation to the data provided by the GIS.

In section 2 the system GEOAIDA is introduced, which is used to generate an interpretation based on photographs or other raster data of the earths surface. The introduction of GIS data into the process of an analysis is described. The system is using prior knowledge, which is formulated in a semantic description, in our case a semantic net.

The conception of GEOAIDA (Bückner et al., 2001) focuses on the interpretation of remote sensing data. Hereby an exclusive hierarchical description of the problem in a semantic net has been chosen. The possibility to add so-called holistic operators is integrated. The holistic operators can reduce the problem created by the complexity of combinational diversity. Holistic image processing operators can be connected to all nodes of the semantic net. The task of holistic operators in GEOAIDA is to divide a region into sub-regions and to reduce the possible alternative interpretations if applicable. The structural interpretation of the sub-regions follows and can verify or disprove the hypotheses.

Interpretation of remote sensing data means to transform input data into a structural and pictorial description of the input data, which represent the result of the analysis. The structural description generated from the generic semantic network has the same structure as the semantic network. This form of result description makes it possible to access information of the object type, the geo-coordinates and all other attributes calculated during the analysis. The result and all intermediate results are stored in XML-descriptions and are used for the validation or falsification of the GIS data (Bückner et al., 2002).

Based on experiments in (Pakzad, 2002) in this approach a transition graph is also used which describes temporal dependencies for changes of a class. This enables the user to formulate temporal a priori knowledge and to use it in connection with an older GIS during the automatic analysis. Thus in addition to the structural a priori knowledge, knowledge about temporal dependencies can be used to refine decisions in the interpretation process.

Section 3 describes the methods used to classify areas into several classes which have a meaning in topographical databases. The approach is divided in two parts, a structural approach based on building detection and a holistic approach based on texture classification. The combination of both results leads to the final interpretation. A comparison of the automated interpretation to ground truth data based on the current ATKIS2001 is carried out. The results will be shown in section 4 leading to the conclusions in the end.

2 SYSTEM DESCRIPTION

Initial starting point of the quality surveillance is the interpretation of a current aerial image. The interpretation uses a knowledge base. Knowledge is provided to the system by a semantic network, GIS information, which is in general older than the current aerial image and a state transition diagram (Fig. 1). In the following the newly introduced state transition graph is described. The analysis operation using the semantic network is topic of section 2.2.

2.1 State Transition Graph

The transition graph in Fig. 1 models the expected transition of objects in the suburban area of Hannover. The acquisition of development areas is an important item of GIS databases. Transitions between all vegetation classes including *grassland*, *farmland* and *forest* are possible. Developments of an area from one of the vegetation classes to the classes *settlement* and *industry* are expected. The changing of a class *settlement* or *industry* to one of the vegetation classes is implausible and therefore these hypotheses will be rejected during the analysis. This leads to a falsification of vegetation areas, if the interpretation decides for *settlement* or *industry* on earlier vegetation areas.

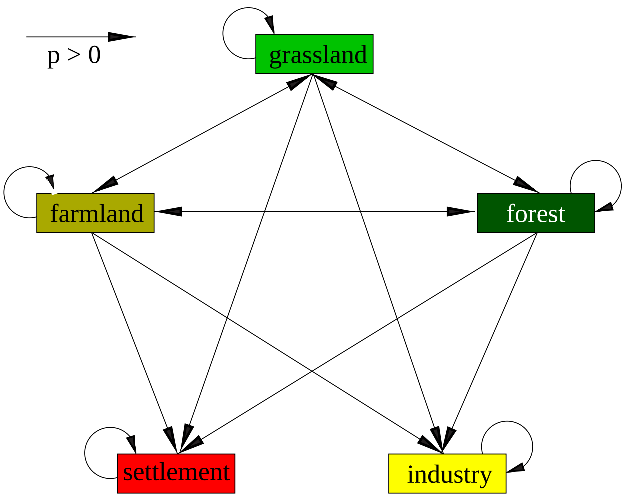

Figure 1: State transition diagram of land use in the suburban region of Hannover.

The semantic network, which models all elements of the investigated scene, contains nodes and edges, whereas nodes represent the objects and edges represent the relations between objects. During the analysis, the hypotheses are generated according to the structure of the semantic network, a previous GIS and the state transition graph. The GIS data is used to initialise the disputed regions and for each of these hypotheses are generated. The hypotheses network has the same structure as the semantic network. This way the a priori semantical knowledge is introduced into the analysis. Then only the plausible hypotheses, according to the state transition diagram, are selected. The hypotheses have to be verified and in case of conflicting hypotheses the most probable decision is chosen. The verification process includes the instantiation of the hypothetical objects from the image data including a qualitative measure of accordance with the model.

The result of the interpretation consists of a structural description of the investigated scene which can be presented as a thematic map offering variable level of detail. At the end of the analysis an update of the input GIS data is possible with use of the automatic interpretation result.

2.2 Analysis

Two analysis steps can be distinguished, the so-called top-down-step and the bottom-up-step. The top-down-analysis is model based and generates a network of hypotheses based on the semantic network and the possible state transitions defined in the state transition diagram. The data driven bottom-up-analysis instantiates the hypotheses, performs a grouping and thereby verifies or falsifies the hypotheses. The result of the bottom-up-analysis is the instance network, which is a complete description of the scene and has the same structure as the input semantic network.

2.2.1 Top-down step The analysis starts by using a holistic top-down-operator that segments the scene according to the investigated GIS data. This pre-segmentation uses the state transition diagram to expand only plausible hypotheses and therefore accelerates the analysis, because only the plausible hypotheses have to be regarded in the progressing analysis for this region.

In general the top-down-operator has the task of subdividing a region into subregions and to build hypotheses for the expected objects. The expansion of the hypotheses network is realised recursively from the upper nodes in the semantic network to the lower nodes. For this purpose any segmentation operator can be integrated which creates hypotheses for the subregions.

For all generated subregions georeferences exist to preserve the global reference that way. Holistic operators can reduce the class affiliation possibilities of a region without introducing knowledge about the exact component parts or structural configuration of the region. An example for a holistic operator is the splitting of a region into subregions by means of a consistency measurement. The choice of texture permits the posing of a restricted number of hypotheses, which are relevant for the investigated region.

2.2.2 Bottom-up step If the top-down-analysis reaches the leaf nodes, the analysis turns from model based interpretation to data based interpretation (bottom-up). The bottom-up-operator has the following tasks:

- Extraction of objects, object attributes and measurement of single objects.
- Grouping of object parts from the lower level and providing it as one object to the next higher level.
- Representation of the results in label images.
- Calculation of a quality description for the objects.

The bottom-up-operators can be created in external programs, designed by the user of GEOAIDA. The user can also generate a generic operator and specify special tasks in an internal functional descriptive language, e.g. to specify the number of nodes, calculate attributes or introduce neighbourhood relations of the child nodes to mention some possible tasks. There are also some standardised bottom-up-operators for the instantiation of objects. If different hypotheses for one region are generated, the decision is made by the bottom-up-step according to the expected structure or quality values provided by the extraction algorithms.

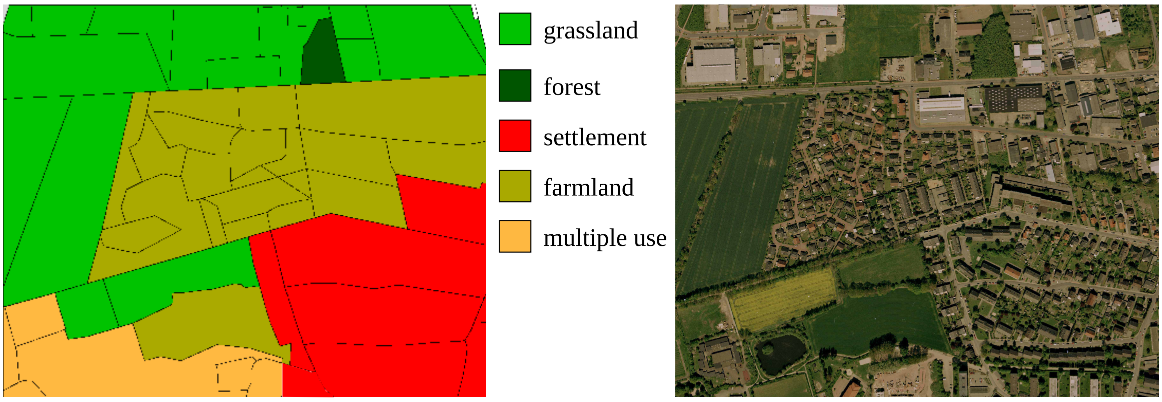

Figure 2: Synthetic ATKIS1969 (left) and input aerial image of year 2001(right) (©LGN)

3 CLASSIFICATION

Since the analysis uses as part of the a priori knowledge a previous GIS, ATKIS1969 has been manually synthesized from an aerial photo of the year 1969.As a matter of fact, a real ATKIS does not exist for the year 1969. The aerial photo of 2001 to be analysed and the GIS used to support the interpretation (here ATKIS1969) are shown in Fig. 2. The spatial resolution of the image is 0.3m.

The synthetic ATKIS1969 can be finally compared with the classification result of the aerial image of 2001 in order to point out changes, which have occurred from 1969 until 2001.

During the analysis two different complementary approaches are followed. Firstly, a textural analysis of the scene takes place to decide between the classes in Fig. 1. Secondly, a structural analysis of the image is carried out, which searches for the most important items of settlement and industry areas, houses and halls. The two approaches are realised by different operators in the top-down- and bottom-up-step.

3.1 Textural analysis

The textural analysis uses a segmentation algorithm described in (Gimel'farb, 1997). The algorithm was extended to use a multiresolution technique to segment the image. The classification algorithm has to learn the properties of the classes with manually created training regions for the classes in the state transition diagram Fig. 1. In this approach the classes farmland and grassland are combined to one unitary class, because the textural differences between them are too small and the class features strongly overlap. The learning steps are:

- Learn the texture algorithm with the training areas in 4 subsampling resolution levels resulting in 4 parameter files.
- Based on the parameter files the segmentation of the input image in all resolution levels is performed.
- Evaluation of the segmentation for each class in all resolutions.
- Calculation of an evaluation matrix.

As a result of the learning process 4 parameter files and an evaluation matrix are derived. The segmentation is done by a top-down-operator that begins with the lowest resolution and processes the higher resolutions level by level. It uses the parameters derived from the training areas. The steps of the top-down texture operator are:

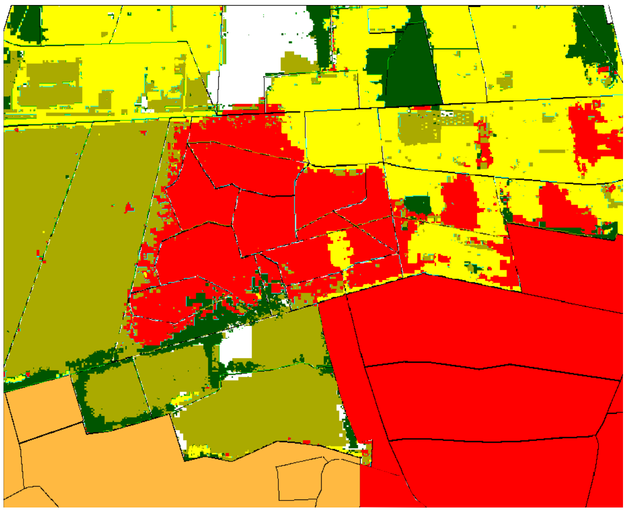

Figure 3: Holistic analysis based on texture (legend in fig. 7)

- Segmentation of the input image in all resolution levels using the parameter files.
- Calculation of a resulting segmentation using the segmentations in the different resolution levels and the evaluation matrix.

The learning step determines the resolution level on which a class gains significant signatures. From the evaluation matrix can be derived in which resolution level a texture can be differenciated. The resolution with the best separation characteristic may differ from one class to another, the classification of inhabited areas is, for example, significantly better in the lower resolutions and therefore preferably used.

The learning step is a crucial part for the effectiveness and correctness of the derived results. This step is preferably done by a human operator, who manually defines training areas for the desired classes. The automatic generation of training areas by the use of GIS data is possible. The training areas for the desired classes can be taken from the regions of a GIS and be used to train the classifier. This has to be done for a few areas, whereas the resulting classification definitions can be used for similar images, e.g. the complete set of images of a flight. Since the fully automatic derivation of training areas sometimes leads to training areas containing a mixture of classes, the separability of the classes is not as good as it is with manually defined areas. The

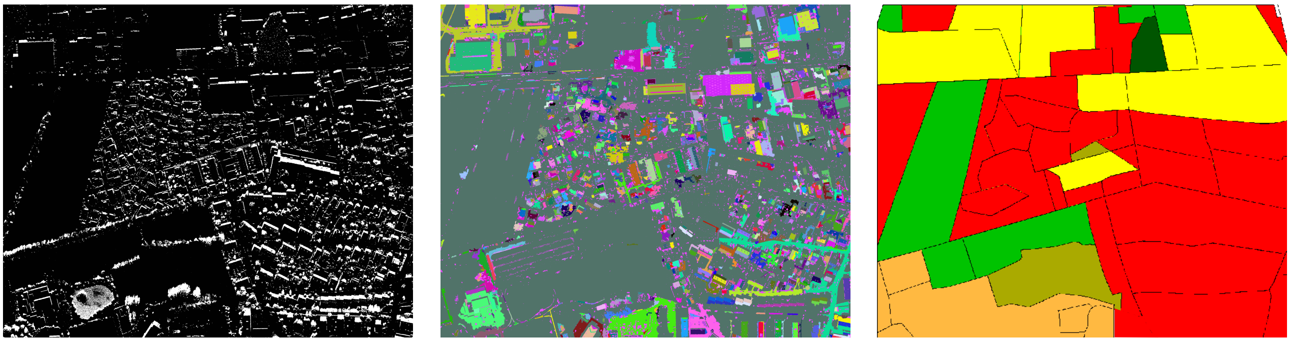

Figure 4: Structural analysis based on detected buildings. From left to right: shades, roofs, classification result

advantage is a higher level of automation which is an important feature of the system. For the results presented here manually defined training areas are used.

In Fig. 3 the result of the top-down texture operator is shown. The different classes are assigned according to the legend in Fig. 7. The comparison of ATKIS1969 and the textural analysis of the input image shows a change from grassland and farmland to industry and settlement area. The areas of *hybrid use* (an ATKIS class containing settlement and industry) and the settlement in ATKIS1969 were not considered for change, because the change to a vegetation class was excluded in the state transition diagram.

3.2 Structural analysis

The structural analysis is based on finding houses and halls, which are modeled as complex structures consisting of different parts. It assumes an illumination model shown in Fig. 5. The angles α and β are calculated from the exact date and time of the image capture and the sun angle. Hypotheses for shades and roofs are generated using two different image segmentation operators, initiated by top-down-operators. To validate these hypotheses during the bottom-up-step instances of roofs are grouped with one or more shades. The neighbourhood relations regard the illumination model. Instances of houses and halls are generated, the decision between these two is depending on the size of the building.

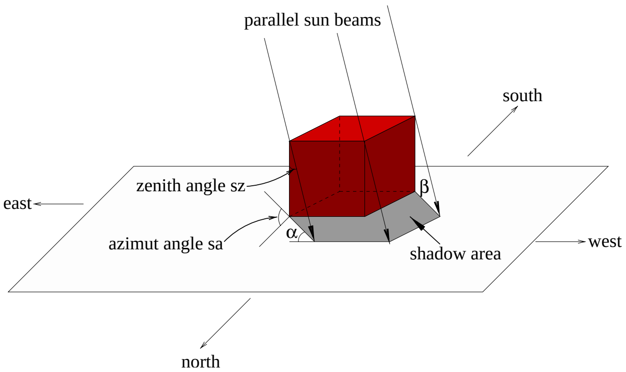

Figure 5: Illumination model for houses and halls

The hypotheses for shade of buildings are derived with a threshold decision in the image. The threshold can be calculated from the histogram automatically, so that images with different illumination can be processed. Since shades are by large not visible in a green color channel, the green color has been masked during shade detection. The shade hypotheses fulfill the following conditions:

- value $<$ threshold
- hue$< 90^\circ \vee$ hue $> 150^\circ$

The extracted shade hypotheses are labelled white in Fig. 4. In this example shade hypotheses for shadows of trees and parts of the lake in the lower part of the image are included, which are rejected during the following grouping in the bottom-up-step.

The roof hypotheses are generated in a more complex procedure. Here the so-called color structure code (Priese et al., 1994), (Rehrmann and Priese, 1998) is used to segment the entire image. Additionally greenish areas are masked out and roofs are accepted only in the other parts. An additional size criterion selects roof hypotheses of a plausible size. The hypotheses for roofs are shown in the middle image in Fig. 4.

During the bottom-up-analysis different conditions have to be fulfilled for shades and roof hypotheses. Shades generated by houses and halls have a limited area, so shade e.g. near a forest can be excluded. The compactness and orthogonality of roof labels is additionally measured to validate these hypotheses.

In the next bottom-up-step, the grouping of shades and roof labels to validated buildings is performed. The neighbouring position of a shade to a roof has to fulfill the illumination model. Sometimes it is not possible to differentiate between the roof of a building and e.g. an adjacent parking area. In that case the expected size for a building is exceeded, does not fulfill the model, and the grouping is rejected during the analysis.

In Fig. 4 the result of the structural analysis is shown in the right image. The resulting building hypotheses are divided into houses and halls by the area of the objects. The next grouping step decides whether the area is containing settlement or industry. If many industry halls have been found the classification decides on industry, as opposed to settlement.

3.3 Combination of the textural and structural analysis

The results of the two approaches, the structural and the holistic approach, are combined to verify or falsify the provided GIS information. The two approaches lead to different measures of quality. The structural approach identifies complex objects by using a combination of different clues and the structure of objects. A texture classification, which is a holistic operator, leads to a pixel-wise assignment of classes.

For this purpose the relevant features of the classes have to be investigated. Based on the expected features, quality measures used to support or reject decisions are used in the bottom-up step.

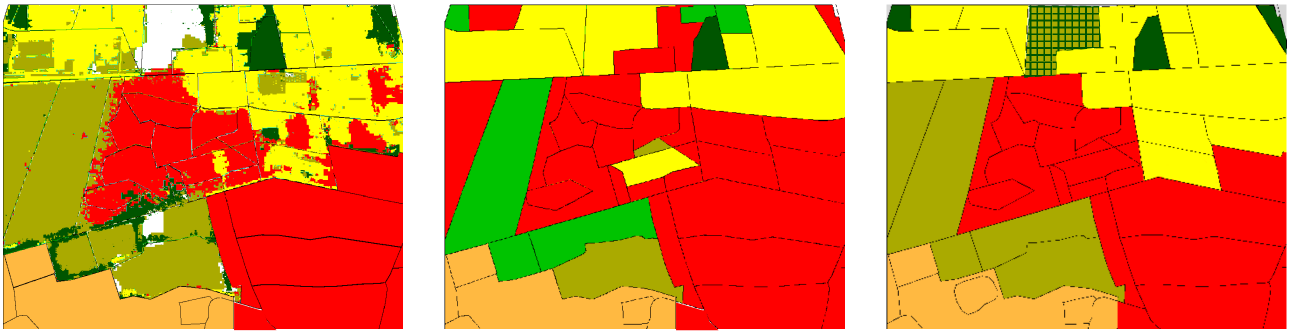

Figure 6: Classification result from left to right: holistic classification, structural classification, combination of both (legend in Fig. 7)

The quality values for the extracted objects are propagated in the bottom-up-step. For buildings, a combination of the quality values for the fulfillment of the model are used, e.g., orthogonality, compactness and size. The required neighbourhood relations have to be fulfilled. The decision based on the structural analysis alone is depicted in the middle image of Fig. 6. The textural analysis of the region leads to an overlap. The amount of overlap is used as quality measure. Since the quality measures are evaluated by operators that are specifically designed for the classes, different measures can easily be introduced and combined for the classes. The combined result for the two approaches can be found in the right image of Fig. 6.

For the considered classes the following decisions are used:

class	structural analysis	textural analysis
settlement	houses detected	settlement
industry	halls detected	industry
forest	no houses/halls	forest
grassland	no houses/halls	grassland/farmland
farmland	no houses/halls	grassland/farmland

For the classes defined in the GIS a verification or falsification is possible. Settlement and industry are verified by means of the buildings found. Vegetation classes are falsified if houses or buildings are found in the region. This is based on the definition in the ATKIS objects catalogue. Within the vegetation classes forest can be identified and verified. Farmland and grassland are not supposed to contain forest. The two classes are not well separable by the texture operator in aerial images. If additional data like infrared images can be used an improved pixel-wise classification with the additional channels leads to more reliable results. Anyway the differentiation between these classes is not of interest in this approach since the focus is on the changes of settlement and industry. The latter are the classes of high importance that are to be correct in ATKIS.

4 RESULTS

To test the developed algorithm, the automatically generated interpretation is compared to ground truth data. Since ATKIS 2001 is available, this data is taken as ground truth. On the left side of figure 7 the original ATKIS data of 2001 is depicted. The automatically generated result of GEOAIDAis shown on the right side.

The result of the automated analysis of the aerial image taken in 2001 and ATKIS2001 are mostly identical, but a few differences remain. The detected differences are numbered from 1 to 7 in Fig. 7. There are two explanations for these differences, either the interpretation is incorrect or the available ATKIS2001 data is incorrect. A detailed comparison leads to the regions where an update of the available GIS is required. In the following the differences between the ATKIS of 2001 and the automatically derived result are reviewed.

1: The classification detects a change from grassland to forest for this region (see Fig. 7). A manual inspection shows that the derived result is correct and ATKIS has to be updated.

2: A lake in the ATKIS of 2001 as part of a hybrid use region was not taken into account in the automatic quality control. The class hybrid use can not easily be verified automatically since the definition depends on the kind of usage of the buildings which cannot be derived from aerial images.

3: No differentiation was possible between the classes grassland and farmland, since the texture operator returns both in one class. The texture operator can be learned with both classes and a segmentation and differentiation is possible. Often even a human interpreter can't distinguish between grassland and farmland as a result of the same appearance in the image. For this approach the differentiation is irrelevant.

4: The texture operator was not able to decide for one of the classes farmland or forest, because both classes had the same quality value.

5: The region was correctly classified to industry and leads to the necessity of an update of ATKIS.

6: ATKIS contains the class settlement, GEOAIDA has decided for industry. The region contains only one very big apartment house, so the region has texture like an industry area. Furthermore the region is very small and no other buildings exist, so the structural analysis finds only one big building in it. The automatic quality control system has detected a change from a vegetation class to an industrialised area.

7: The interpretation leads to forest, a manual inspection shows that GEOAIDA has decided for the right class and ATKIS has to be updated.

The results derived for this test area show a good correspondence to the ground truth in the manual inspection. Differences between the ATKIS data and the situation in the aerial image lead to the areas which have to be updated. Most of the regions have been

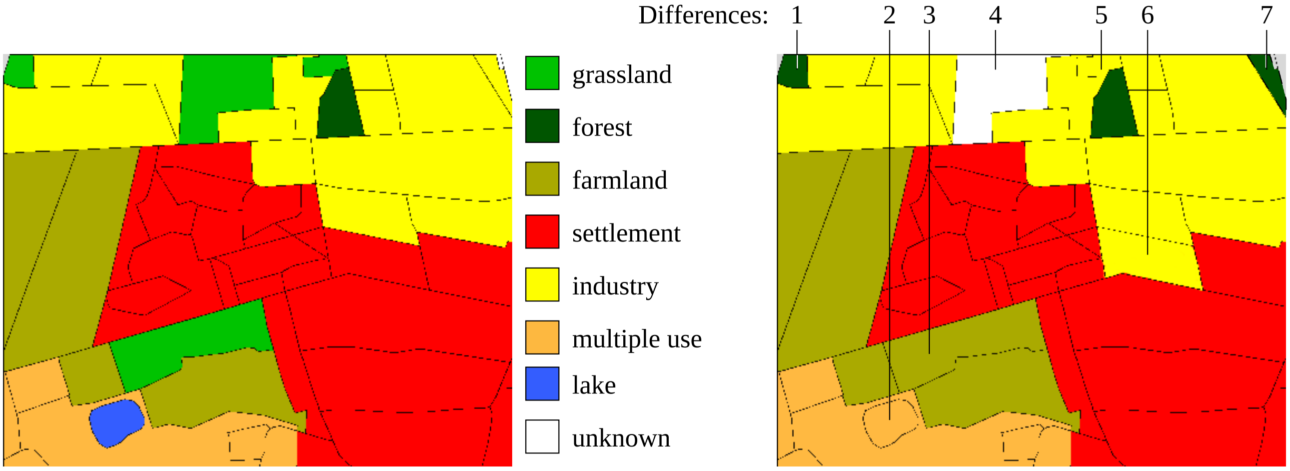

Figure 7: Comparison of the current ATKIS2001(left) with the automated classification result from aerial image of 2001(right). The numbers in the right image indicate differing regions and are explained in the text.

confirmed. Therefore the automation of quality control is possible with the system. The results may be refined in future by introduction of other data sources and operators for the control of other classes. The derived automation is helpful for an updating of GIS data, since the overall correctness draws the attention correctly to conflicting situations and reduces the necessary time to find incorrect classified regions in ATKIS. A human operator can concentrate on the parts in which change or inconsistency has been detected.

5 CONCLUSIONS

The developed approach to verify the quality of GIS data uses the knowledge based interpretation system GEOAIDA. The knowledge base is used to introduce a priori knowledge in form of a semantic net and GIS data. The semantic net models relationships between objects and primitives extracted from images. The system was expanded with a state transition diagram to handle temporal dependencies. The temporal dependencies were used to find relevant changes in the GIS data. By modeling an older state of the GIS data and a following change detection a good correspondence to the present day situation was achieved. The state transition diagram may also be used to perform a detection of temporal changes of objects as found in monitoring tasks.

The simulated quality control of GIS data shows good results as explained in section 4. The combination of structural and textural features leads to different types of information, which can be used for the quality surveillance of GIS data. Since the system is open and has the possibility to integrate any type of image processing and extraction algorithm it can be adopted to other tasks. The knowledge base can be changed easily by setting up a semantic net and adaption of operators. Already existing processing algorithms can be recombined to solve different tasks.

In this approach the focus was set to land use analysis. Other possible applications are the detection of alteration, environmental studies, the development of urban areas and the examination of natural disasters.

The discussed analysis is actually tested and evaluated as a part of a practical application for the quality assessment of GIS data, which integrates additional quality control for roads by use of a road extraction system.

REFERENCES

AdV-Arbeitsgruppe ATKIS, 2002. ATKIS-Objektartenkatalog Basis-DLM. 3.1 edn, AdV.

Busch, A. and Willrich, F., 2002. Quality management of atkis data. In: H. T. M. Orhan Altan (ed.), Proceedings OEEPE/ISPRS Joint Workshop on Spatial Data Quality Management, OEEPE/ISPRS, Istanbul, Turkey.

Bückner, J., Pahl, M., Stahlhut, O. and Liedtke, C.-E., 2001. GEOAIDA a knowledge based automatic image data analyser for remote sensing data. In: CIMA 2001, Bangor, Wales, UK.

Bückner, J., Pahl, M., Stahlhut, O. and Liedtke, C.-E., 2002. A knowledge-based system for context dependent evaluation of remote sensing data. In: L. J. V. Gool (ed.), DAGM-Symposium, Lecture Notes in Computer Science, Vol. 2449, Springer, Zurich, Switzerland.

Gimel'farb, G. L., 1997. Gibbs fields with multiple pairwise pixel interactions for texture simulation and segmentation. Rapport de recherche RR-3202, INRIA, Sophia Antipolis France.

Pakzad, K., 2002. Knowledge based multitemporal interpretation. In: Proc. ISPRS2002, Graz, Austria.

Priese, L., Klieber, J., Lakmann, R., Rehrmann, V. and Schian, R., 1994. New results on traffic sign recognition. In: Proceedings of the Intelligent Vehicles Symposium, pages 249–254. IEEE, 1994.

Rehrmann, V. and Priese, L., 1998. Fast and robust segmentation of natural color scenes. In: ACCV (1), pp. 598–606.