VERIFICATION OF A DIGITAL ROAD DATABASE USING IKONOS IMAGERY

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ABSTRACT

The IPI is working in a project funded by the German Federal Agency for Geodesy and Cartography (BKG) where a system for the automated verification and quality control of a nationwide road database is designed and implemented. In this paper we present results from the application of IKONOS images for the given task. Besides the verification of an existing road database, the performance of plain road extraction using the IKONOS data is analyzed.
The following aspects are of major interest: how reliable and how complete can roads be delineated using a line-based road extraction algorithm? Does the incorporation of the infrared channel increase the overall quality compared to the PAN-channel? Comparing IKONOS and aerial imagery: what about reliability and efficiency regarding the automated verification workflow?
In order to answer these questions several experiments applying different parameter settings in the existing system are carried out. A reference road-net was manually digitized by an operator. The achieved results from automatic road extraction and database verification are promising. It turns out that the use of the NDVI-image leads to a reliable and accurate road extraction in open landscape areas. According to our experiences the results for the verification of the given road network are comparable to results achieved with aerial imagery.

1 INTRODUCTION

The availability of high resolution optical satellite imagery appears to be interesting for geo-spatial database applications, namely for the capturing and maintenance of geodata. Recent works show that the geometry of IKONOS or Quickbird imagery are accurate enough for mapping purposes (Büyüksalih and Jacobsen, 2005). Compared to traditional aerial imagery, satellite data has the advantage to be captured more frequently. On the other side both methods suffer from a weather dependency; but here the aerial imagery benefits from the fact that the moment for capture can be chosen more flexibly. The alternative use of mostly weather-independent Radar images is very interesting for map capturing and updating, but not treated in this paper.

In Germany ATKIS (Authoritative Topographic Cartographic Information System) represents the official topographic reference dataset for the whole country. The dataset with the highest resolution is called DLMBasis. Its content approximately equals a topographic map of a scale of 1:25,000 and is not generalized. The DLMBasis is maintained and updated by the 16 German Federal States, but the BKG (German Federal Agency for Cartography and Geodesy) is responsible for merging this data for the whole country and derives maps of smaller scale from the DLMBasis. In this context the question whether the data delivered by the states are accurate enough, i.e. whether it keeps the required quality standards is a practical question, which has to be answered. Quality comprises completeness, positional accuracy, attribute correctness and temporal correctness for each object (Zhang and Goodchild, 2002).

During verification the database objects are compared to the reference: the positional accuracy and the attribute correctness can be checked using the extracted objects. The completeness and temporal aspect is only considered partly as just commission errors are identified. In a following update process, new or modified road objects not included in the database are extracted. By this means also completeness and temporal correctness are fully considered. In the present paper only the verification is addressed.

For the verification of the given database a semi-automatic workflow has been setup at BKG. The Knowledge-based Photogrammetric-Cartographic Workstation (WiPKA-QS[1]) supports an operator in the comparison of the ATKIS DLMBasis database to reality, i.e. to an up-to-date remotely sensed image. The main task is to increase the efficiency compared to a completely manual workflow, but also to keep high reliability. The aim is not to replace the operator, but to automatically find as much as possible correct objects and leave it to the operator to solve cases where the algorithms did not find enough evidence for the correctness of the respective object. The focus is on the verification of settlement areas and road objects as these are amongst the most frequently changing object classes. In (Busch et al., 2004) details and results are given.

In order to reduce costs for this verification the BKG strives for using standard image data, in most cases also delivered by the Federal States in the form of orthoimages being captured in a three to five year turn. The drawback of using this data is that one is bound to this long update period and as the ATKIS DLMBasis is mainly updated using the same data, the verification is not completely independent from the capture. It is attractive to incorporate satellite data into this workflow for these two reasons.

The focus of this paper is to analyze the capability of optical satellite data (in this case IKONOS) to be used for road extraction in general, but also to be applied in the established workflow in the named project for road database verification. The quality control of area objects is not discussed here.

2 APPROACHES TO ROAD EXTRACTION AND ROAD DATABASE VERIFICATION

2.1 Road Extraction

Many approaches for road extraction from images with a ground sampling distance of 1m or larger exploit the fact that road objects appear as bright lines in the images, having a limited curva-

[1] In German: Wissensbasierter Photogrammetrisch- Kartographischer Arbeitsplatz zur Qualitätssicherung

ture and a nearly constant width. This model is quite insensitive against objects on the roads such as cars or different road surfaces.

For the experiments carried out here the algorithm introduced in (Wiedemann and Ebner, 2000, Wiedemann, 2002) is applied, which uses such a model. The underlying line extractor is explained in (Steger, 1998). The initially extracted lines are evaluated by fuzzy values according to attributes like length, straightness, constancy in width and constancy in gray values. Finally, single lines are grouped in order to derive a topologically correct and geometrically optimal path between seed points according to some predefined criteria. The decision if extracted and evaluated lines are grouped into one road object is made corresponding to a collinearity criterion (allowing a maximum gap length and a maximum direction difference). This approach is designed for open landscapes, mainly because objects disturbing the given line-based road model in remotely sensed images are not modeled. Those objects like vegetation, buildings or cars are called local context objects.

A different approach is introduced in (Dial et al., 2001) and (Gibson, 2003). Here results from a multispectral classification, edge detection and a texture classifier are combined to extract roads in IKONOS imagery. Each operator is applied in different scales of the image. Examples were shown for urban and suburban areas in the US. One has to keep into mind that the grid like structure or the road network in these areas supports automatic road extraction.

2.2 Verification of ATKIS Road Database

In this paper the system described in (Gerke et al., 2004) is used. Similar to other approaches like (Bordes et al., 1997, Zhang and Baltsavias, 2002) information regarding the global context, i.e. the environment where the respective roads are situated (open landscape, built-up, forest), is gained from the GIS database to enhance the road extraction: parameter settings are optimized for the context classes. The system is able to check whether the requested geometric accuracy ($\pm$3m) is maintained by the ATKIS road objects. Commission errors (roads are present in the database, but cannot be identified in the reference image) are detected. Roads not currently being registered in the database but which can be found in the image (ommission errors) are not detected so far.

The road extraction algorithm described in the section above is used but modified for the given tasks, especially by applying individual parameters for the given global context areas and the extraction for each road object separately. If the complete ATKIS object can be reconstructed (considering the allowed accuracy), it gets accepted and rejected otherwise. This method is embedded in a two-stage graph-based approach, which exploits the connection function of roads and leads to a reduction of false alarms in the verification. In the first phase the road extraction is applied using a strict parameter control, leading to a relatively low degree of false positive road extraction, but also a large number of roads will be rejected although being correct. For the second phase the latter objects are examined regarding their connection function inside the road network. It is assumed that accepted roads from the first phase are connected via a shortest path in the network. All rejected roads from the first phase fulfilling important network connection tasks are checked again in a second phase, but with a more tolerant parameter control for the road extraction. Experiments have shown that the proposed two-step graph-based approach enhances both efficiency and reliability compared to a single verification pass, cf. (Gerke et al., 2004). As up to now only the mentioned road extraction software is included, the system is also restricted to open landscape areas.

3 EXPERIMENTS CARRIED OUT

Data Parts of an IKONOS scene captured in June 2003 near Darmstadt/Germany are used. The testarea has an overall size of approximately 4 by 4 km^2 and mainly covers open landscape and built-up areas. The four color channels are pan-sharpened and the image has been transformed into the same coordinate system as the ATKIS data. The necessary projection from the originally delivered system into the target coordinate system was carried out using salient junctions of the road network as identical points and a DTM. Thus, it is not possible to check for all projection errors contained in the ATKIS road database. Nevertheless the overall accuracy is good enough for the given purpose. For detailed information on the generation of orthophotos from IKONOS imagery cf. (Jacobsen, 2002).

The ATKIS road objects (number: 1555 total, 1040 in open landscape) have an overall length of 173 km (total) and 136 km (in open landscape). Additionally, an operator has digitized roads in the image in order to have an independent verification of the ATKIS database and some reference data for the plain road extraction available. Besides the PAN-image a NDVI-image has been computed for the scene. To reduce the computation time for the road extraction, the images are clipped to 2 by 2 km^2 thus resulting in 4 images for each channel. The PAN-images used for the experiments are shown in Fig. 4, the NDVI-images in Fig. 5[2].

The numbering of images is as follows:

1	2
3	4

3.1 Road Extraction

Although the used road extraction algorithm Is designed just for open landscape areas, in the experiments carried out here, no differentiation has been made between built-up, open landscape and forest areas. By this means the usability of the infrared channel concerning the increase of efficiency and reliability should be analyzed: enables this channel (respectively the derived NDVI-image) a better discrimination between road and background images even if disturbances by context objects are relatively likely, compared to the PAN-channel? For the road extraction using the PAN channel two parameter-sets where defined: a more 'strict' one, where it is to be expected that the completeness is relatively low, but the extracted roads are more correct than in the 'tolerant' extraction run. When road extraction is applied in NDVI image one can exploit the fact that mostly no vegetation can be found on roads (except for some kinds of paths). This leads to low NDVI-values on the road surface. In case of high NDVI-values in adjacent regions, the contrast is quite high. Therefore in one experimental setting the road brightness model was restricted to 'dark', i.e. the roads need to be darker than the background. In a second setting also a 'light' model (roads are brighter than the background) was applied. The line extraction algorithm used here is not able to extract step lines, i.e. the background on the one side of the line is brighter than the line, and the background on the other side is darker than the line.

Using the manually captured road data and applying the evaluation method proposed in (Wiedemann et al., 1998) the quality measures *correctness* and *completeness* are achieved. Additionally the geometric (planimetric) accuracy is calculated (*RMS*).

3.2 Verification of ATKIS Road Database

Experiments for the verification of the ATKIS DLMBasis road database are carried out also using the PAN- as well as the NDVI-

[2] All large images are located at the end of this paper

images. The verification was applied for the whole scene, because the verification result should be comparable to the result from the road extraction carried out separately. However, the verification is applied a second time for the open landscape areas.

A means to evaluate the verification results is to define a confusion matrix, where reference and the verification result are compared. The types of error and their impact on the practical semi-automatic workflow are given in Tab. 1. The operator who is inspecting the road verification results just concentrates on the objects which have been rejected. Therefore the number of true positives should be relatively high since it indicates efficiency. The false positive errors are undetected errors and thus should be minimized.

	Verification result: acceptance	Verification result: rejection
Reference indicates: correct	True Positive (Efficiency)	False Negative (Interactive final check)
Reference indicates: incorrect	False Positive (Undetected errors)	True Negative (Interactive final check)

Table 1: Confusion Matrix

The aim of the experiments carried out here (both plain road extraction and verification of a given ATKIS road database) is not to yield the best results for every image, i.e. to trigger the parameters for every image separately. We want to concentrate on the differences between results from NDVI and PAN imagery, different context regions and in general between road extraction and road verification. Therefore, the parameters are not chosen for perfect results, but for comparable ones.

4 RESULTS

4.1 Road Extraction

PAN-image Results from the more 'strict' parameter setting are shown in Tab. 2 and in Fig. 6. The outcome from the experiment where the 'tolerant' parameters for the road extraction were applied are shown in Tab. 3 and in Fig. 7. In the images green lines indicate correct roads, i.e. they match the reference. Red indicates omitted objects: roads from the reference were not extracted. Finally, blue are commission errors: objects have been extracted, but they cannot be found in the reference. Green and red lines reflect the completeness measures and the worse the correctness, the more blue lines will be present.

Image no.	Completeness	Correctness	RMS $[m]$
1	0.51	0.35	3.46
2	0.50	0.32	3.38
3	0.47	0.31	3.57
4	0.52	0.32	3.52

Table 2: Road extraction, PAN-image, Parameter-Set A (strict)

Image no.	Completeness	Correctness	RMS $[m]$
1	0.72	0.37	3.50
2	0.72	0.30	3.55
3	0.56	0.27	3.49
4	0.66	0.28	3.60

Table 3: Road extraction, PAN-image, Parameter-Set B (tolerant)

It is apparent that although the resulting correctness just decreases marginally from the strict to the tolerant setting, the completeness increases by approx. 50%. Some salient roads are not extracted due to the missing step-model implementation. Especially in the middle southern part this can be observed.

NDVI-image The results from the road extraction in the NDVI channel, where just the 'dark' model was applied are shown in Tab. 4 and in Fig. 8. The results from the same parameters, but also applying the 'light' road model is shown in Tab. 5 and in Fig. 9.

Image no.	Completeness	Correctness	RMS $[m]$
1	0.36	0.60	2.62
2	0.34	0.54	2.16
3	0.23	0.61	3.26
4	0.34	0.62	2.21

Table 4: Road extraction, NDVI-image, P.-Set A ('dark')

Image no.	Completeness	Correctness	RMS $[m]$
1	0.60	0.41	3.84
2	0.62	0.39	3.84
3	0.51	0.46	4.16
4	0.63	0.45	3.97

Table 5: Road extraction, NDVI-image, P.-Set B ('dark' and 'light')

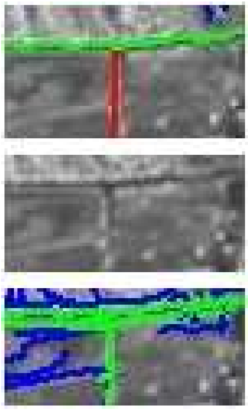

Figure 1: Examples for extraction in NDVI-images. Upper: using 'dark' model, middle: original image (NDVI), lower: using 'dark' and 'light' model

Some interesting facts can be observed here: apparently just applying the 'dark' model (A) leads to less (≈ -50%), but therefore more correct (≈ +30%) roads compared to the case when both models are used (B). The geometric accuracy is much better. In Fig. 1 typical examples are shown. The upper image shows the result when just the 'dark' model is used, the middle picture shows the original NDVI-image and on the lower image the result from the fusing of both models is depicted. The road going from East to West perfectly fits to the 'dark' model and was extracted correctly in both extraction runs. But the vegetation along this road fits to the 'light' model and therefore was extracted in the extraction run where both models were applied. This explains the observed differences: the geometric accuracy is worse because of these additional objects, the completeness increases and the correctness decreases as many objects are extracted additionally - both correct and incorrect ones. It has to be pointed out, that a fusion of the 'dark' and 'light' model also was applied for the PAN-image in both parameter-sets. Here the surface material is responsible for the kind of appearance in the image. According to our experiences both kinds of surface material appear likewise and thus a restriction to one model makes no sense. However, the geometric accuracy and the correctness would increase, if just one brightness model is applied in road extraction from PAN-imagery.

Comparison The shown results allow some intermediate conclusions:

- If just the 'dark' model is used, the NDVI-image allows to extract more roads correctly and accurately than using the PAN-image.

- The correctness is very weak, it is less than 50% for all settings, except for the NDVI-image if just the 'dark' model is applied.

- If the parameter setting gets more tolerant the completeness increases more than the correctness decreases.

Concerning the differences regarding a road extraction in built-up areas a typical example is shown in Fig. 2. In the result obtained with the PAN-imagery (left) obviously the completeness is much higher than in the result from NDVI-image (right), but the correctness is bad. This is explainable by the fact that in the NDVI-imagery the homogeneity inside the large structures like house-blocks or shadows thrown by houses is higher than in the PAN-imagery and therefore less lines are detected. In the forest area which is situated in the center of the images this can be also observed. Therefore, one additional conclusion is: in built-up areas it is easier to trim the algorithm for a higher reliability (accepting a loss of efficiency) if the NDVI-channel is used. In general a better extraction result can be expected for built-up areas, if the parameters for road extraction are trimmed for this context region; in the experiments carried out here one parameter-set was used for the whole scene.

4.2 Verification of ATKIS Road Database

PAN-image Similar to the experiments conducted above a strict parameter control was chosen as well as a tolerant one for the verification of the ATKIS road database . The results from the more strict settings (A) are shown in Tab. 6, the respective results from the tolerant settings (B) in brackets. The left side of the Table shows the results for the whole image, the right side concentrates on the open landscape areas. In Fig. 10 and 11 the respective images are shown. Green lines indicate that the system raised the decision 'acceptance', red lines indicate an automatic rejection. One can observe, that in general the number of false positive decision, i.e. not detected errors, is relatively large. The reference data was captured just using the IKONOS imagery: in some cases the operator could not clearly identify road objects (due to weak contrast, occlusions . . .). Often such uncertain objects are part of the ATKIS road database and they were found automatically, but they were not captured for the reference and thus leading to false positive errors.

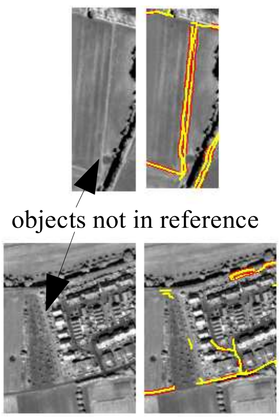

Figure 3: Examples for a FP error (top) and a correct rejection decision (bottom)

In Fig. 3 typical examples are shown: The arrows are pointing to objects where the operator decided not to digitize a road object, but in both cases an ATKIS road object is present. In the upper image the road verification algorithm (here: PAN-image, Set B) extracted a road and therefore accepted the ATKIS road object although it is not in the reference, thus leading to a false positive error. In the lower image a similar situation is shown, but here the road extraction algorithm did not find a road and therefore rejected the respective ATKIS object, leading to a true negative decision. These examples point out that even the manual verification of such an ATKIS road dataset using the present imagery does not necessarily lead a to clear result. However, the experiments carried out here enable a relative comparison between results from different input images and parameter-sets.

Comparing the results in Tab. 6 some differences are showing up. *Whole image vs. open landscape*: the efficiency (=true positive) increases from whole imagery to open landscape, the reliability (false positive) remains constant. This result was expected as the road extraction algorithm is not optimized for built-up areas. *Strict vs. tolerant parameter control*: The number of false positives increases from approx. 4.9% to 6%($\approx$ +20%), also the number of true positives increases from approx. 45% to 58% ($\approx$ +28%). This means, the increase of efficiency is higher than the loss of reliability. Again, some road objects which are apparently correct and visible are not accepted due to the missing ability to extract step-lines.

NDVI-image Similar to the experiments for the plain road extraction the verification of the ATKIS road database using the NDVI image was done applying the 'dark' road model (set A) and using a combination of both models (set B). The results are listed in Tab. 7 and in the Figures 12 and 13. The results do not differ significantly if the algorithm is applied to the whole image or the open landscape, except for the setting where both models are applied (B) the efficiency for the open landscape is higher than for the whole image. Obviously the 'light' model leads to more extracted roads in open landscape. This observation matches the conclusions made according to the experiments with plain road extraction.

Comparison In all experiments made here, the results achieved with the NDVI images are better than the results from PAN images: Either the true positive score is similar and the number of false positive errors is less (NDVI compared to PAN) or if the false positive score is similar the respective number of true positives is higher.

5 CONCLUSIONS AND OUTLOOK

An IKONOS scene was used to analyze its usability for road extraction and road database verification. From the experiments carried out the following conclusions can be drawn:

- As most roads in open landscape appear as dark line surrounded by light areas (vegetation) in NDVI-images, the reliability of road extraction is very high if this property is exploited.
- The performance of road extraction and road database verification is higher if NDVI-images are used compared to the use of PAN-imagery.
- The results for road database verification regarding the efficiency are comparable to results achieved with aerial imagery (Gerke et al., 2004). The reliability is worse, but mainly because of the shown problems with the manual identification of road objects in IKONOS imagery. It seems that in some situations it is easier for an operator to extract roads in aerial images than in IKONOS imagery; the better resolution may give additional hints regarding the existence of a road object. This is a general issue, not restricted to (semi-) automatic extraction and verification methods, and has to be kept in mind for practical applications.
- In built-up areas the use of NDVI-images reduces false extractions compared to the use of PAN-images. Anyway, the completeness is weak in both cases due to the mentioned lack in context modeling.
- Some roads are not extracted due to the missing implementation of step-lines extraction. An extension of the algorithm towards the ability to extract those lines would increase the completeness, but it is to be expected that the correctness would further decrease.

The results achieved here motivate to incorporate the road network topology in the task of road database update. The road extraction algorithms can be trimmed to achieve a quite complete road network, but then it is to be expected that a lot of additional

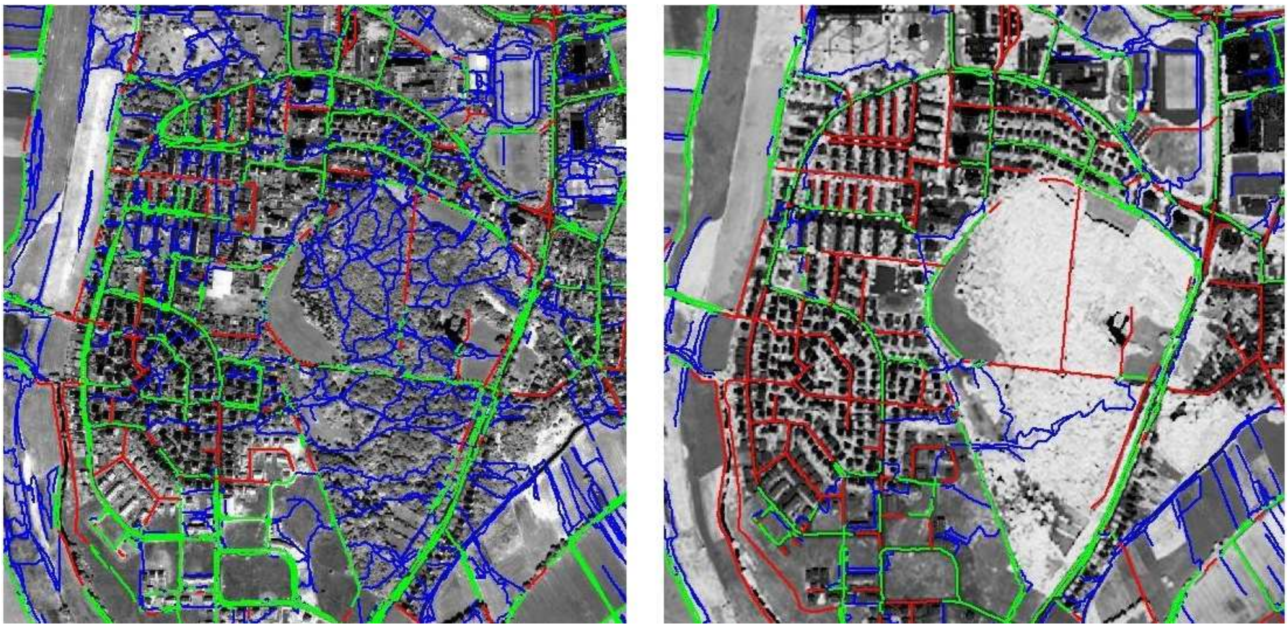

Figure 2: Road extraction in Built-up area. Left: using PAN-image (Parameter-Set B), right: using NDVI-image (B)

	Verification result: acceptance	Verification result: rejection
Reference indicates: correct	0.435 (*0.562*)	0.435 (*0.308*)
Reference indicates: incorrect	0.047 (*0.059*)	0.083 (*0.071*)

	Verification result: acceptance	Verification result: rejection
Reference indicates: correct	0.469 (*0.606*)	0.408 (*0.271*)
Reference indicates: incorrect	0.050 (*0.061*)	0.074 (*0.062*)

Table 6: Road database verification using PAN-image, Left: whole image, Right: open landscape, Parameter-Set A *(B)*

	Verification result: acceptance	Verification result: rejection
Reference indicates: correct	0.510 (*0.579*)	0.361 (*0.292*)
Reference indicates: incorrect	0.037 (*0.051*)	0.092 (*0.079*)

	Verification result: acceptance	Verification result: rejection
Reference indicates: correct	0.515 (*0.607*)	0.364 (*0.272*)
Reference indicates: incorrect	0.036 (*0.051*)	0.085(*0.070*)

Table 7: Road database verification using NDVI-image, Left: whole image, Right: open landscape, Parameter-Set A *(B)*

objects are extracted wrongly. However, the use of the existing road network and the result of a previous verification run can be used to find the correct new roads as these must be connected to this road network. In the future we will concentrate on this issue.

ACKNOWLEDGMENT

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All large figures can be found on the subsequent pages

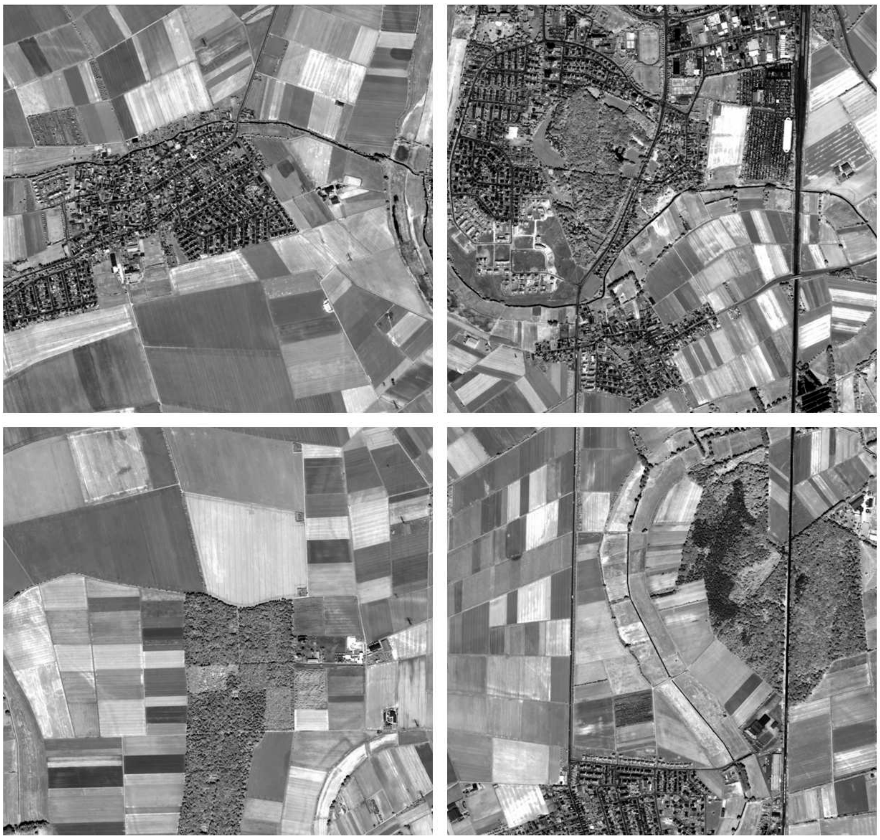

Figure 4: PAN-images

Figure 5: NDVI-images

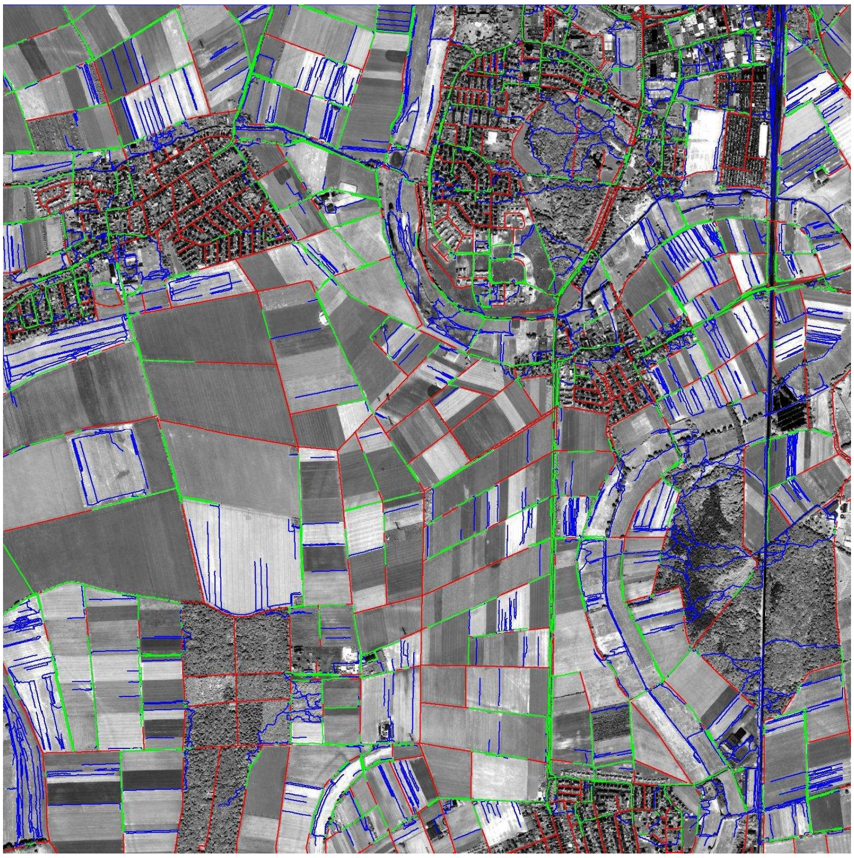

Figure 6: Results: Road Extraction, PAN-image, Parameter-Set A

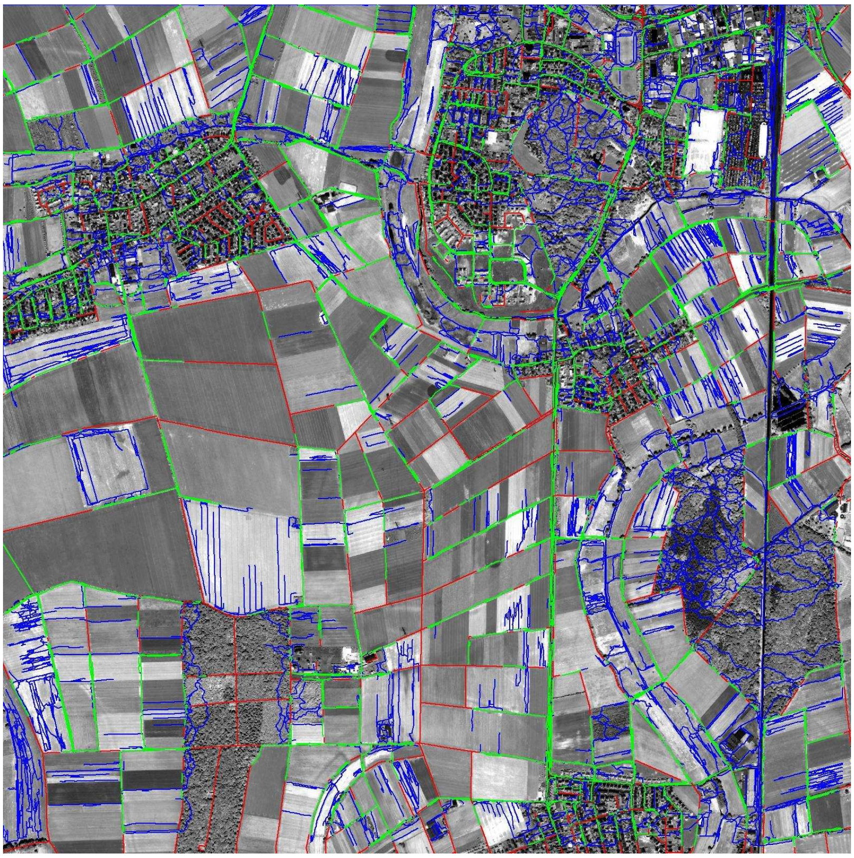

Figure 7: Results: Road Extraction, PAN-image, Parameter-Set B

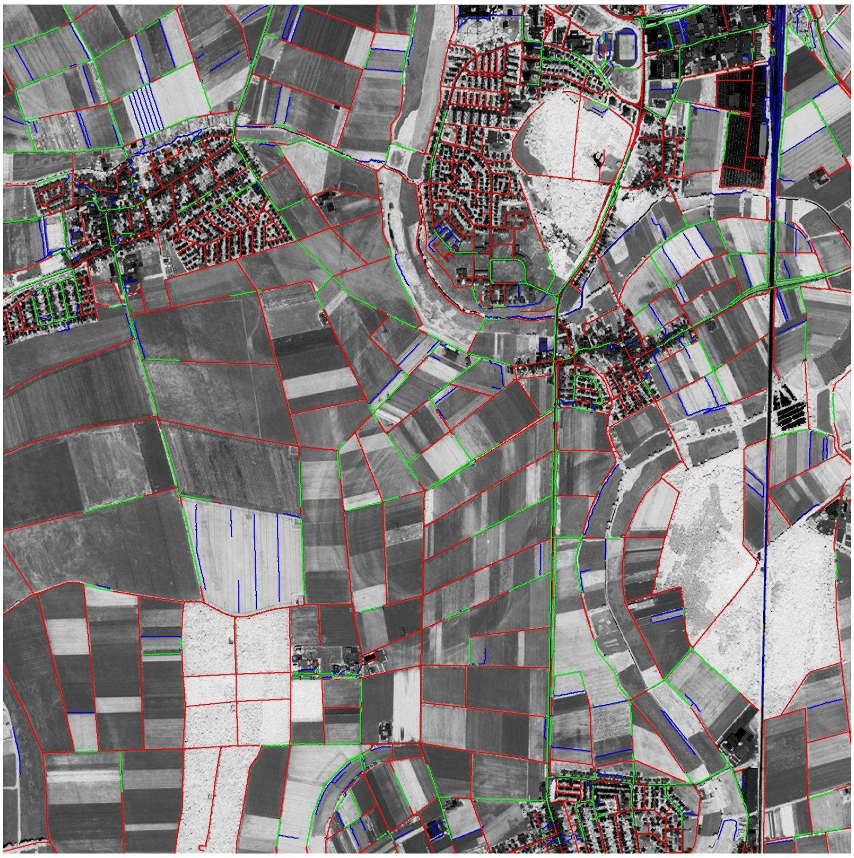

Figure 8: Results: Road Extraction, NDVI-image, Parameter-Set A

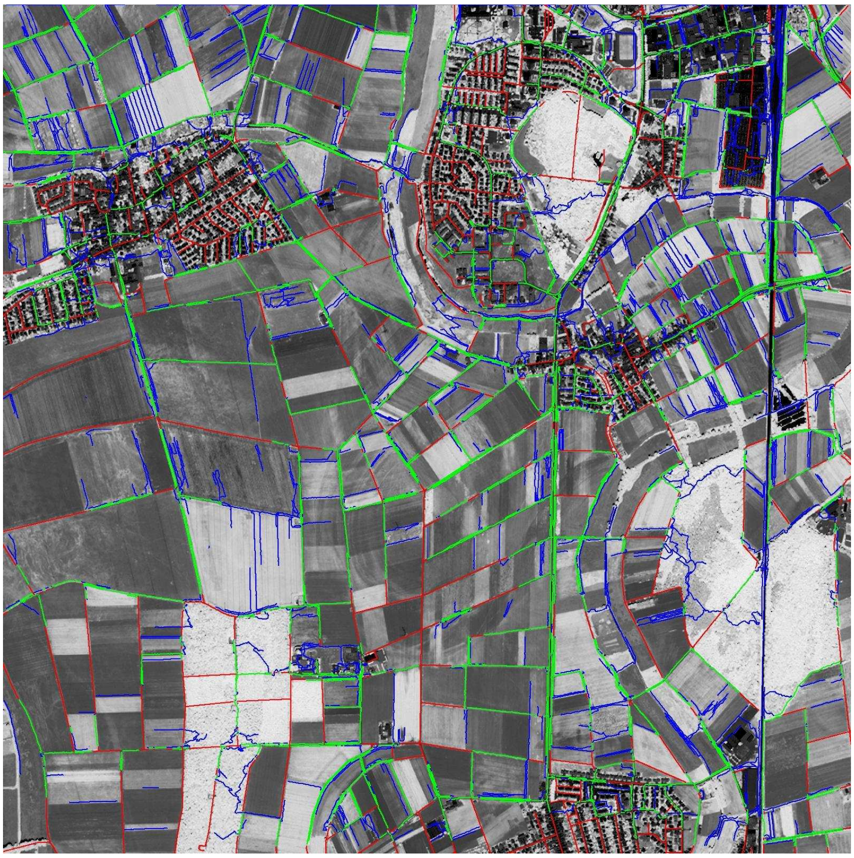

Figure 9: Results: Road Extraction, NDVI-image, Parameter-Set B

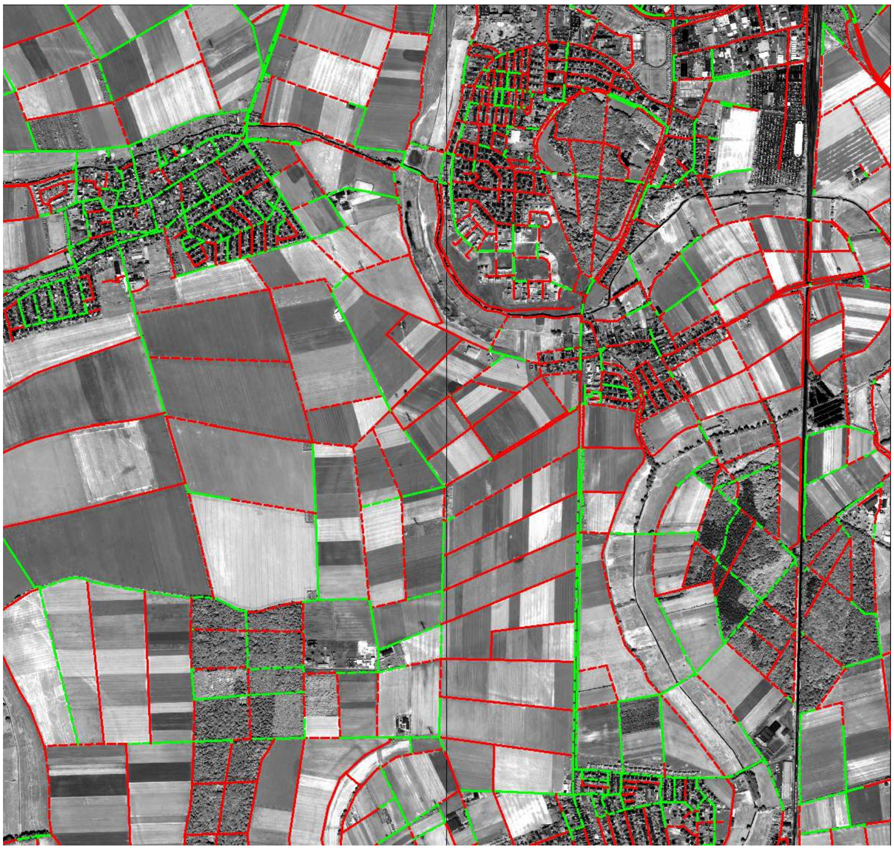

Figure 10: Results: Road Database Verification, PAN-image, Parameter-Set A

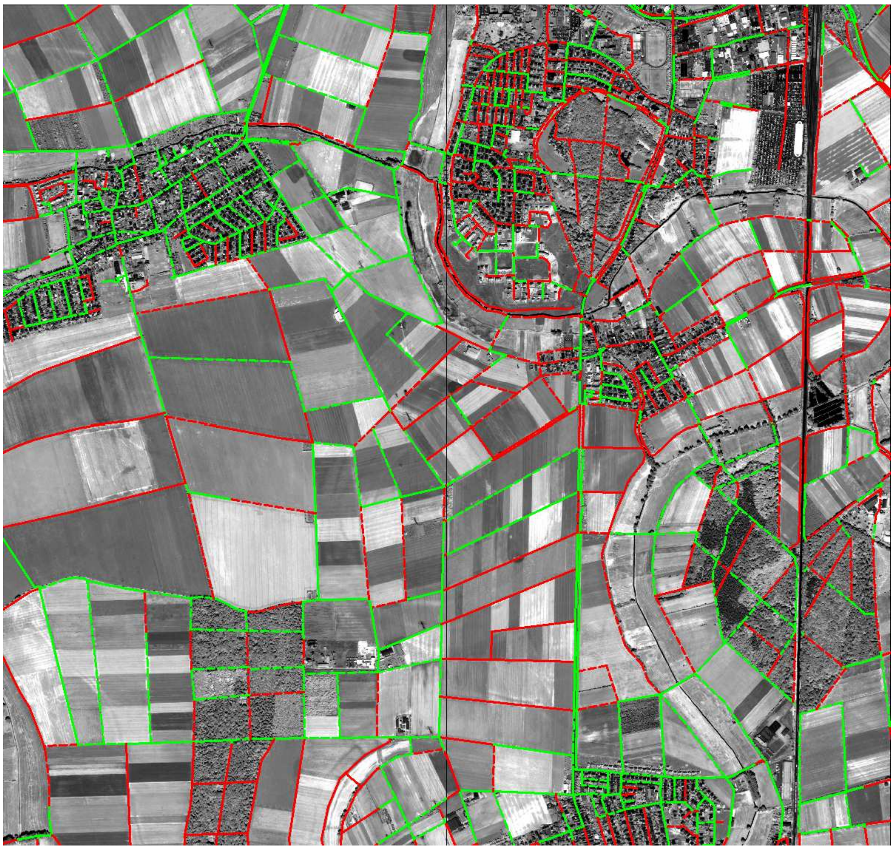

Figure 11: Results: Road Database Verification, PAN-image, Parameter-Set B

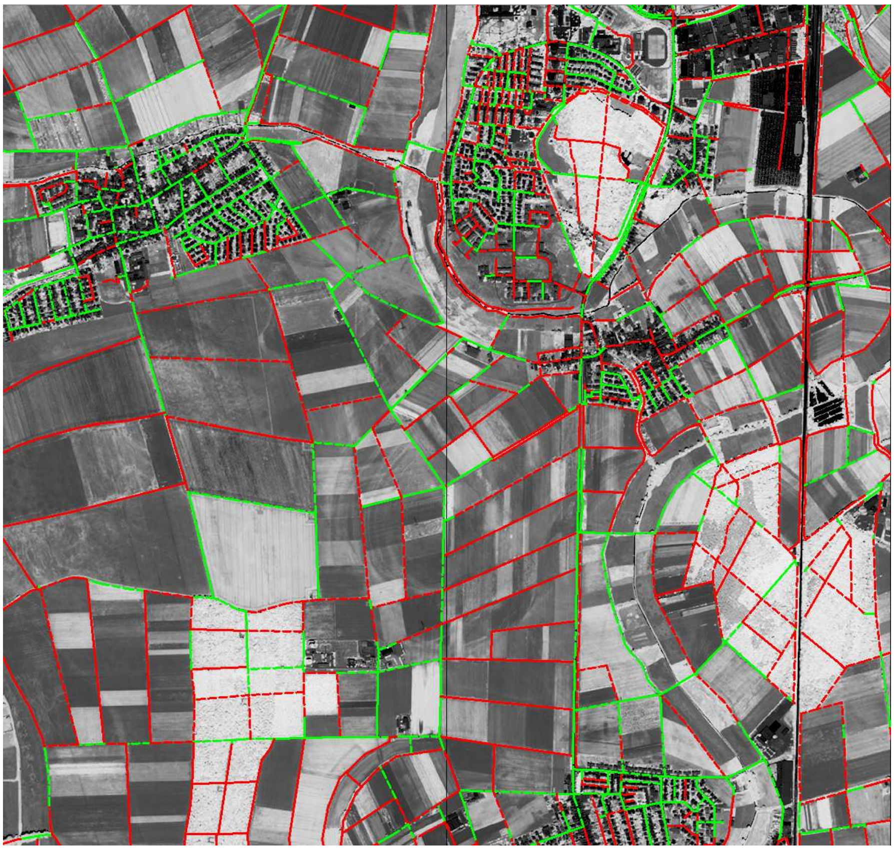

Figure 12: Results: Road Database Verification, NDVI-image, Parameter-Set A

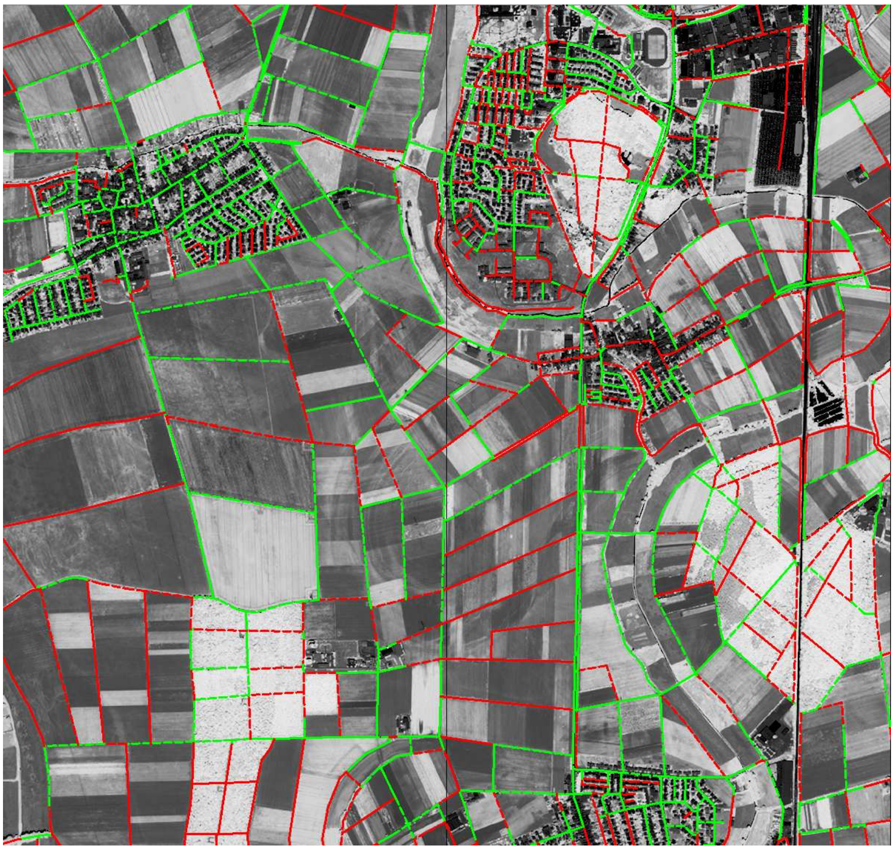

Figure 13: Results: Road Database Verification, NDVI-image, Parameter-Set B