# MODELLING THE INTEGRATION OF HETEROGENEOUS VECTOR DATA AND AERIAL IMAGERY

M. Butenuth and C. Heipke

Institute of Photogrammetry and GeoInformation, University of Hannover
Nienburger Str. 1, D-30167 Hannover, Germany
{butenuth, heipke}@ipi.uni-hannover.de

**KEY WORDS:** Integration, Modelling, GIS, Image Analysis, Vegetation

**ABSTRACT:**

The integration of different data sources is an important task to obtain overall solutions in many areas, for example geo-scientific analysis, updating and visualisation. The specific task in the presented approach is the integration of heterogeneous vector data with imagery to enhance the Digital Soil Science Map of Lower Saxony (Germany) with automatically derived field boundaries and also with wind erosion obstacles. This data is needed for various soil science problems and the agricultural sector (e.g. precision farming). The main focus is the integrated modelling of prior knowledge from a GIS together with the objects of interest and their neighbouring objects in one semantic model. Besides the relations between the different layers of the semantic model, the relationships between the different objects are of interest. The GIS-objects road, river and railway represent the geometry position of parts of the field boundaries and can build a framework for an automatic extraction approach for the remaining boundaries. They also represent search areas for wind erosion obstacles, which are located parallel and near to roads, rivers and railways. Additionally, all wind erosion obstacles are field boundaries or at least parallel with a short distance in between.
The paper presents our approach to modelling the landscape with respect to the given tasks. First results of the extraction of field boundaries have been derived and demonstrate the potential of the proposed solution.

## 1. INTRODUCTION

In geo-scientific analysis, updating and visualisation the use of different data sources is necessary to obtain overall solutions in tasks such as the estimation of potential erosion areas, soil-monitoring or road construction. The combined utilisation of this frequently heterogeneous data involves complex data handling concerning unequal representation and quality. This fact is caused by the different requirements of vector and raster data and the different data models of the vector data, because of different methods for collecting the data in the past. Therefore, the integration of different heterogeneous data becomes more important for (1) a mutual use of existing data for various problems, i.e. information contained only in one data set is linked to another, (2) to complete and enhance a data base thematically to be able to deduce new thematic information and (3) to verify existing data automatically, for example by exploiting up-to-date imagery, regarding their quality, to correct them or to improve their accuracy.
This paper focuses on the integration of vector and raster data to enhance geo-scientific vector data with additional objects extracted from aerial imagery. The specific task is to enhance and refine the digital Soil Science Map of Lower Saxony in Germany (c.f. NLFB 2003) with automatically derived field boundaries and wind erosion obstacles. Such data is not available, but nevertheless important for various soil science problems. One task is the derivation of wind erosion risk fields, which can generated with input information about the prevailing wind direction, wind shelters, soil parameters, field width and a tolerance field length (Thiermann et al. 2002). Another application area can be found in the agricultural sector, where information about field geometry is more and more of interest, for example in precision farming (c.f. Grenzdörffer 2002).

In the mentioned context data integration will be accomplished with automated image analysis methods based on digital colour-infrared (CIR) images, which is an important development in data acquisition and update (Englisch and Heipke 1998). The use of prior knowledge is essential to facilitate automated object extraction from aerial imagery (e.g. Bordes et al. 1996, Koch et al. 1997, Baltsavias 2002). The prior knowledge consists of an initial scene description of the German ATKIS DLMBasis (Authoritative Topographic Cartographic Information System, basic digital landscape model) (Endrullis 2000, ATKIS 2003) and ALKIS (Authoritative Real Estate Cadastre Information System) (ALKIS 2003).
In contrary to several approaches in the automatic extraction of man-made objects such as buildings or roads (c.f. Mayer 1998) the extraction of vegetation objects from high resolution imagery is still not in an advanced phase (c.f. Borgefors et al. 1999, Heipke et al. 2000, Straub and Heipke 2001). Prior work in the area of field boundary extraction is very marginal; Löcherbach (1998) presented an approach to refine topologically correct field boundaries, but not the acquisition of new ones.
Modelling the heterogeneous vector and raster data together with the object classes in a semantic net, in order to obtain an overview of the numerous relations between the objects to be extracted and to integrate prior knowledge, is the core of this paper and will be described in the next section. Afterwards, the strategy for the extraction of field boundaries and wind erosion obstacles used in the introduced approach is presented. Some initial examples and results in the area of automatically derived field boundaries are given in section 4 to demonstrate the potential of the proposed solution. Finally, further work required will be highlighted in the conclusions.

## 2. MODELLING THE INTEGRATION OF VECTOR DATA AND IMAGERY

### 2.1 General

Modelling the integration of the heterogeneous vector data with imagery in one semantic model is an essential prerequisite for successful object extraction. The scene descriptions for integrating the different data models of the vector data with the objects in the imagery as well as the modelling of these objects are the content of the current work. We differentiate in the semantic model an *object layer*, consisting of a geometric and a material part, a GIS part and a Real World part, and an *image layer* (c.f. Figure 1) (Tönjes 1999). The relations between the different layers ("concrete of") of one object are referenced in the image layer to CIR-images, which are generated in summer, when the vegetation is in an advanced period of growth. This constraint is introduced, because the information content of the imagery regarding automatic vegetation extraction is best at this time period. The objects of interest, field boundaries as well as the wind erosion obstacles, are described in the different models by their characteristics and appearance (c.f. Figure 1, right part) in an overall context with the other neighbouring and thus influencing objects.

### 2.2 Prior Knowledge

The use of prior knowledge plays a particularly important role, which is represented in the semantic model by an additional GIS-layer, in this case by the vector data of ATKIS DLMBasis and ALKIS. Exploiting this additional knowledge facilitates object extraction in a far-reaching manner:

- Firstly, information about field boundaries and wind erosion obstacles are only of interest in the *open landscape*. Therefore, regions not belonging to the open landscape (e.g. urban, water, forest) are ignored. Information basis for these purposes is the ATKIS DLMBasis.
- Secondly, we have a closer look to the definition of *field boundaries*: A field area is an acreage of one cultivated plant, and accordingly the field boundary is the borderline between two cultivated plants. Additionally, there can be no doubt, that any kind of roads, railways and rivers represent borders between different fields and consequently are field boundaries, too. This fact is incorporated in the semantic model and the mentioned objects are introduced with a direct relation from the GIS-layer (ATKIS-objects) to the Real World.
- Thirdly, the objects *hedge* and *tree row* are modelled in the ATKIS-data of the GIS-layer, but only, when they are longer than 200 m and lie along roads or are formative for the landscape. Accordingly, only part of the wind erosion obstacles is contained in the ATKIS-objects and the relation from the GIS-layer to the Real World is limited (depicted as dashed lines in the Semantic Model).
- Fourthly, the prior knowledge of the ALKIS-object *parcel boundary* is of interest, because the legal boundaries of the Real Estate Cadastre can give indications for possible field boundaries or at least directions for them.
  It has to be mentioned, that the model of the ALKIS-data is different to the model of the ATKIS-data: For example, the object type road is modelled in ATKIS as a *line* and in ALKIS as an *area*. Therefore, the different vector data has to be made available in an appropriate manner to facilitate the object extraction.

### 2.3 Modelling the objects of interest

The combined modelling of the objects of interest together with the influencing objects in one semantic model leads to

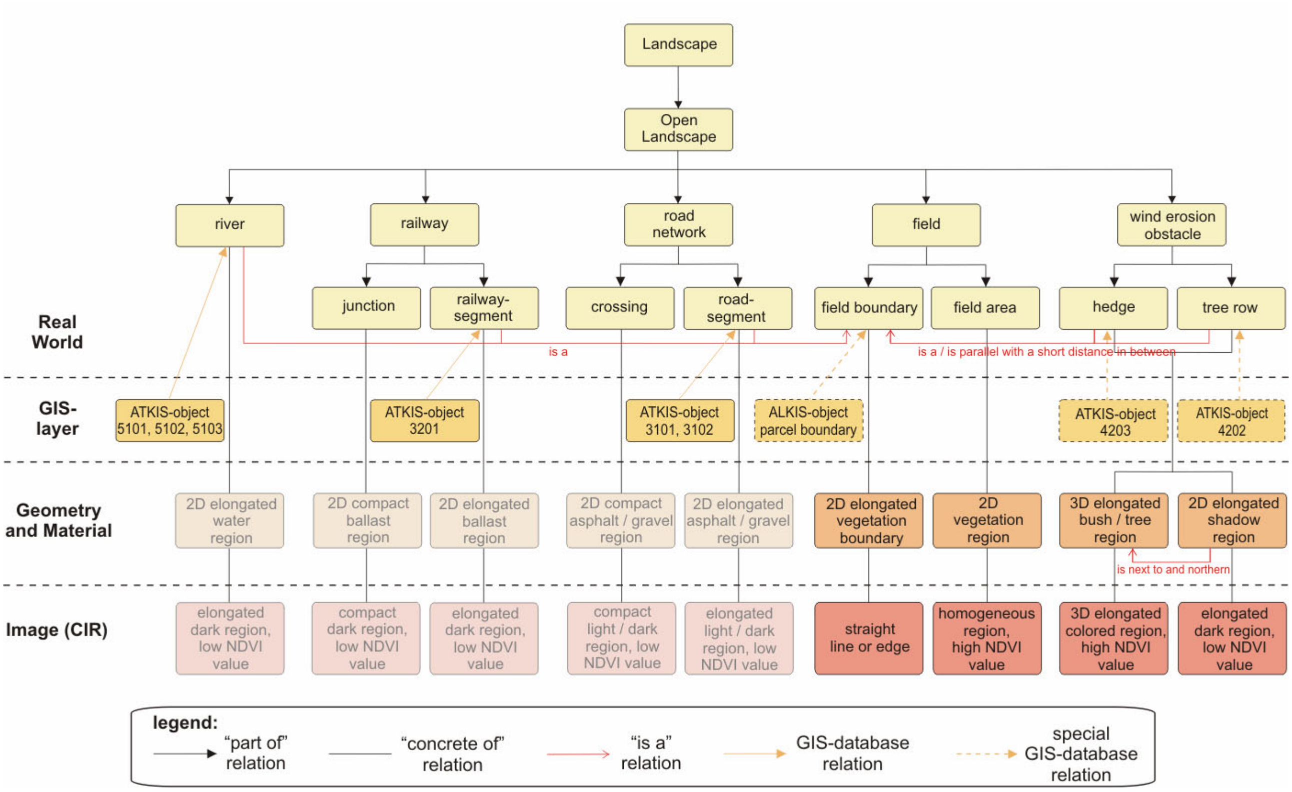


Figure 1. Semantic Model

integrated, holistic and better results, see Förstner et al. (1999) for an overview. In another, but in parts similar task, Butenuth et al. (2003) exploited the knowledge about extracted tree rows during the extraction of roads, which occlude parts of the roads and help to bridge the gaps in the road network.

Consequently, besides the connections between the different layers of the scene description the relationships inside the layers are important (Figure 1): The combined modelling of different object models leads to additional assumptions such as the identity or parallelism in geometry. Moreover, one object can be part of another one, and together they form a network in the real world. In detail we assume, that wind erosion obstacles are not located in the middle of a field, because of disadvantageous cultivation conditions, but solely on the field boundaries. Accordingly, the geometries of these different objects are in part identical or at least parallel with a short distance in between. The last case occurs, when the field boundary is as well, for example, a road. Then the wind erosion obstacle may be on one or both sides of the field boundary.

Generally, all objects important for our task are modelled in the semantic net for the sake of completeness, even if the "concrete of" relations of the objects *river*, *railway* and *road network* are not obligatory, because they are introduced as prior knowledge and not extracted from the images, therefore a modelling in the *Geometry and Material* and *Image* layer is not necessary (transparent diagrams in Figure 1). The object *field* is divided in *field area* and *field boundary* in order to allows for different modelling: On the one hand the *field area* is a 2D vegetation region, which is described in the image as homogeneous region with a high NDVI (Normalised Difference Vegetation Index) value, and on the other hand the *field boundary* is a 2D elongated vegetation boundary, which is described in the image as a straight line or edge. Both descriptions lead to the desired result from different sides.

The object *wind erosion obstacle* is divided in *hedge* and *tree row*, because there is different information from the GIS-layer available. Afterwards, both objects are merged, because the "concrete of" relations are identical in modelling. In addition, the wind erosion obstacles are not only described by their direct appearance in geometry and material, but also with the fact, that due to their height (3D object) there is a 2D elongated shadow region next to and in a known direction (e.g. northern direction at noon). Therefore, the "concrete of" relation not only exists of an elongated, coloured region with a high NDVI value, but additional of an elongated dark region with a low NDVI value alongside the real object of interest in a known direction.

## 3. STRATEGY AND APPROACH

### 3.1 General approach

The aim of the strategy in the used approach is to exploit the available and modelled prior knowledge in an optimal manner, because only in this way the complex object extraction can lead to good results. The first step is to mask out the regions in the imagery, where no field boundaries and wind erosion obstacles exist (e.g. urban, water, forest) (c.f. chapter 2.2). The ATKIS-data give the basis for this process and the concentration to the open landscape is possible (c.f. Figure 2, masked regions are coloured in black). The next step contains the exploitation of further prior knowledge to select regions in the open landscape, where modelling of the field boundaries on the one hand and modelling of the wind erosion obstacles on the other hand is relatively easy due to restrictions in complexity of the scene. The strategy at this point is to divide the approach into two different algorithms and to accomplish the extraction of the different objects separately.

At a later date the return to a combined solution is essential due to the mentioned geometrical and thematic similarities of the objects of interest (c.f. chapter 2). Merging the extraction results after a first phase of the proposed approach is necessary to exploit the knowledge about the modelled connections between the field boundaries and wind erosion obstacles. In a continuous process with a common evaluation of the, till then, available results a following enhanced and refined extraction process is possible.

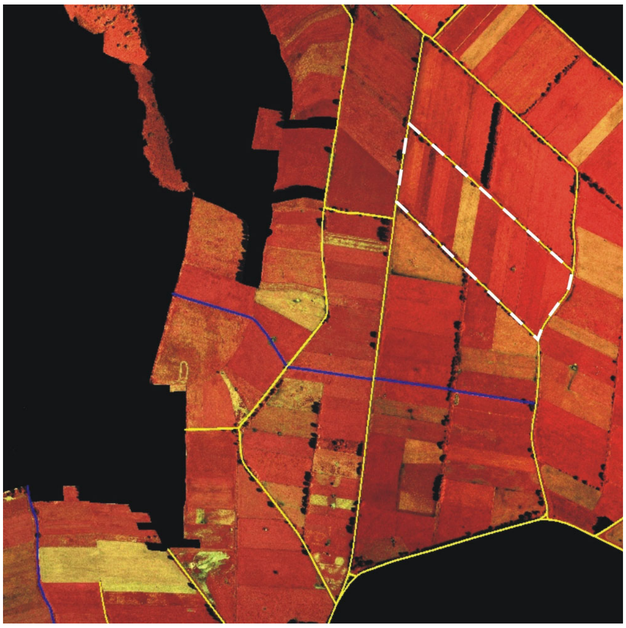

Figure 2. Open landscape with superimposed GIS knowledge: roads are depicted in yellow, rivers in blue. The dashed white line represents one region of interest

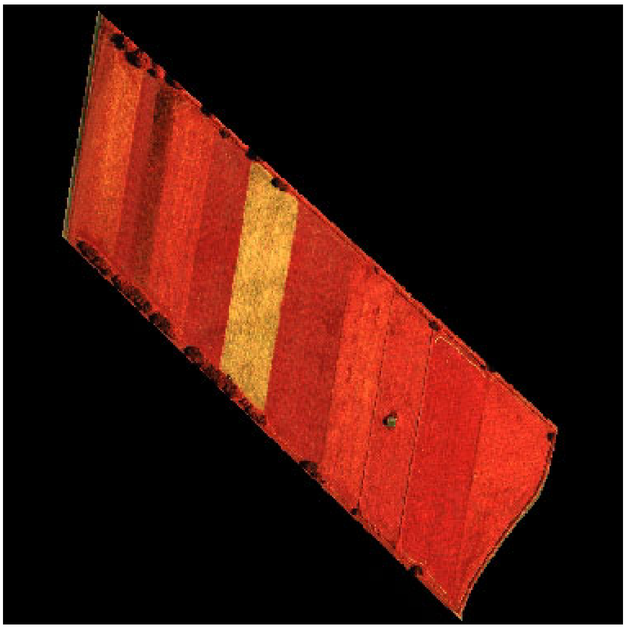

Figure 3. Selected region of interest

### 3.2 Extraction of field boundaries

The selection of regions of interest to facilitate the extraction of field boundaries as mentioned in section 3.1 is implemented with the help of the GIS-data: All introduced line-shaped ATKIS-objects in the model build a common network with the borderlines between masked regions and the open landscape (c.f. Figure 2, roads are depicted in yellow, rivers in blue; railways, hedges and tree rows do not exist in this example). The resulting regions of interest are selected, for example the one with the dashed white lines in Figure 2, separately displayed in Figure 3. The reason for separately processing with each region of interest is the assumption, that there is no significant relation between the directions of field boundaries in the different regions.

The first field boundaries are the borderlines of the selected regions of interest, as defined in the semantic model. These *external boundaries* do not need any further processing. Consequently, the attention is focused to the *internal field boundaries*, to be extracted. The *internal boundaries* have some important similarities, which can be exploited during the extraction process: Each boundary is modelled as a straight edge or line due to advantageous cultivation reasons and moreover, these edges or lines are roughly parallel. This fact can be exploited by searching for one main direction of the field boundaries in the selected region. Conclusions concerning the well-known direction of the external field boundaries to the unknown internal field boundaries are difficult and will not be considered. Also, the knowledge about the fields (e.g. kind of homogeneity, size, quadrangular shape) is not used at that time. Nevertheless, information about the modelled field may have to be incorporated in further processing to yield reliable and better results.

As pointed out in the semantic model, an extraction of edges on the one hand and a line extraction on the other hand is necessary. The *edge detection* is accomplished in the IR-channel of the CIR-imagery (resolution 0.5 m). This channel contains the most significant information about the edges in the imagery. In particular only edges are processed, which represent a certain straightness and length. Afterwards, the direction with the highest frequency of all extracted candidates is selected, and due to the parallelism of the field boundaries in one selected region of interest, only the candidates with an approximately identical direction are selected for further processing. The extraction result of the first candidates for field boundaries is shown in Figure 4 on the left side (each candidate is depicted in a different colour).

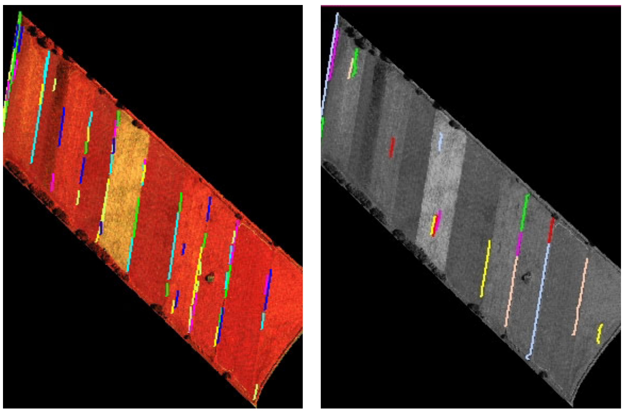

Figure 4. Result of the edge extraction (left) and the line extraction (right)

As described in the semantic model and also visible in Figure 3 on the right side, field boundaries can also appear as lines. Therefore, in a next step a line detection is carried out additionally to obtain an overall solution. In contrary to edge detection, line detection is carried out in the intensity-channel of the image. The candidates for further processing are selected according to length and direction, whereby the main direction of the field boundaries is known from the highest frequency of all directions of the extracted candidates (c.f. selecting main direction of edges). The result of the extracted lines as candidates for field boundaries is shown on the right side of Figure 4.

Usually, extracted edges and lines do not represent the whole field boundary, of course, due to low contrast or occlusions (trees), especially at the border area of the region of interest (c.f. Figure 4). Therefore, a buffer is generated around one extracted object and the ends of the buffer are elongated to the borders of the region of interest (c.f. Figure 5, left side). All extracted objects lying in the buffer are selected and fused to one object. When the length of the new object is longer than a particular percentage of the length of the buffer, one can assume that there is a field boundary and the object is elongated to the borders of the region of interest (c.f. Figure 5, right side); otherwise the object is discarded. This procedure is repeated with all extracted objects in the same manner, the final result is shown in chapter 4. Extracted objects near and parallel to a border of the region of interest are ignored (e.g. on the left side in Figure 4), because in this area there can be no field boundary due to a resulting field with a too small size.

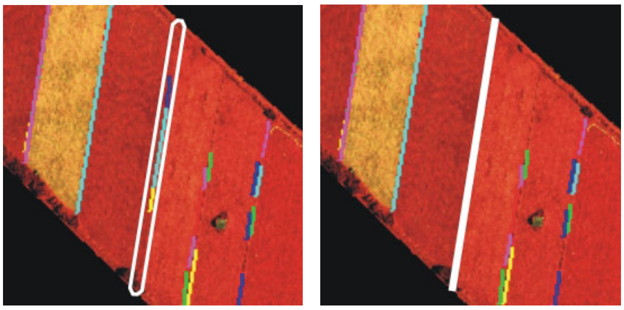

Figure 5. Generating of a buffer around a candidate (left) and processed field boundary (right)

### 3.3 Extraction of wind erosion obstacles

The extraction of wind erosion obstacles is as well as the extraction of field boundaries accomplished with the exploitation of prior knowledge (c.f. chapter 2). The first wind erosion obstacles are the ones, which are represented in the GIS-layer (ATKIS-objects) of the semantic model (c.f. Figure 1). Furthermore, wind erosion obstacles can be located at field boundaries as well as nearby and parallel to roads, rivers or railways. In the first case, the exploited knowledge to be used for the extraction of wind erosion obstacles is similar to the extraction of field boundaries with the only difference, that wind erosion obstacles are more seldom and in general do not reach from one side of the region of interest to the other one. In the second case the network of roads, rivers and railways can be used to generate a search area around these objects in form of a buffer with a particular size to focus the extraction on these regions. More precisely, the buffer must be generated twice: One buffer to each side of the GIS-objects, because in the middle of the well-known objects there can be no wind erosion obstacle. Investigations in this area, also exploiting the knowledge about the connections between wind erosion obstacles and their shadows, are content of the future work. Additionally, the available 3D-information from the images will be used to facilitate the extraction of wind erosion obstacles.

## 4. FIRST RESULTS

In this section first results of the presented approach in section 3 in the area of field boundaries are presented. The final result of the extracted field boundaries in one region of interest is shown in Figure 6. The corresponding reference data are displayed in Figure 7 (field boundaries are depicted in grey, wind erosion obstacles in dashed green lines). One can assume that most field boundaries could be extracted automatically in the shown example, only in the left part two boundaries are missing. In addition, there are no false solutions due to only a few wrongly extracted edges and lines as possible candidates for field boundaries (c.f. Figure 4). Compared to the extraction results of edges and lines in Figure 4 it becomes clear that only a combined extraction approach can lead to a complete and overall solution, because the different models of field boundaries complement one another.

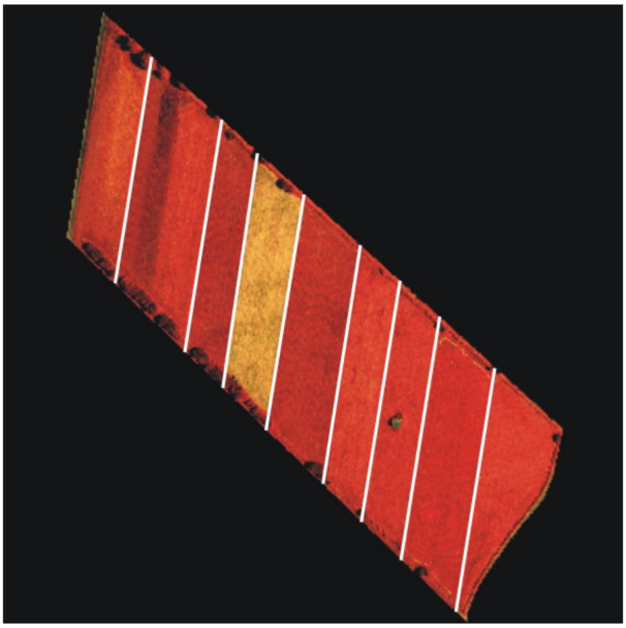

Figure 6. Final result of the extracted field boundaries

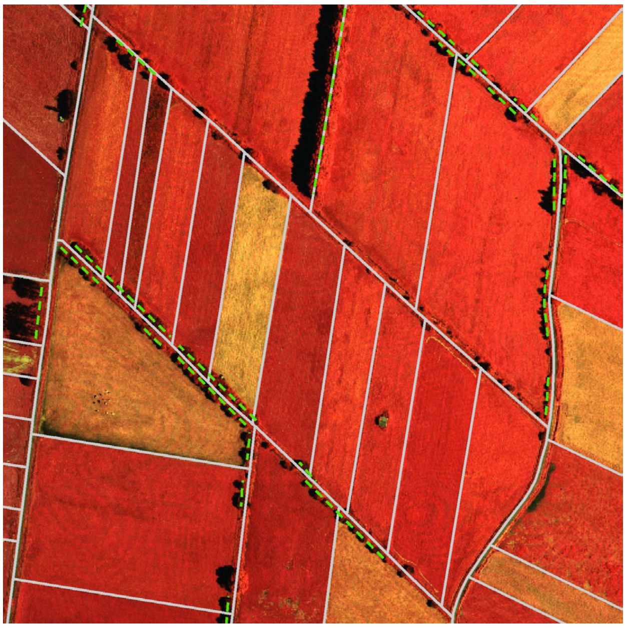

Figure 7. Reference data: field boundaries are depicted in grey, wind erosion obstacles in dashed green

## 5. CONCLUSIONS

In this paper we have presented an approach to integrate different heterogeneous vector data and aerial imagery. The specific task is to extract field boundaries and wind erosion obstacles to enhance the Digital Soil Science Map of Lower Saxony (Germany). Using prior knowledge from a GIS is essential to facilitate object extraction to restrict the complex scene description. The focus is the modelling of the different GIS-data together with the field boundaries and wind erosion obstacles with all influencing objects in one common semantic model to obtain an overall solution. Contrary to the modelled and explicitly used ATKIS (Authoritative Topographic Cartographic Information System) data, the ALKIS (Authoritative Real Estate Cadastre Information System) data are not yet used, a task in future will be to find out if this additional information can be helpful to obtain improved results.

The selection of regions of interest must also incorporate two other possible kinds of regions: On the one hand regions, which have field boundaries with more than one main direction, for example due a change of direction in the selected region of interest (c.f. Figure 2, middle left) and on the other hand regions, which have one (or even more) additional field boundaries running across the region of interest and dividing the region into two parts (c.f. Figure 2, directly located under the region with the dashed white lines).

Investigations in the area of the extraction of wind erosion obstacles will be carried out in further work. The different alternatives to extracting tree rows and hedges will be analysed concerning the use of colour, NDVI value and 3-dimensionality. The last case is of special interest, and the occurring shadow regions next to the wind erosion obstacles in a known direction can help to facilitate the extraction of wind erosion obstacles.

In an enhanced approach the common evaluation of the separately extracted field boundaries and wind erosion obstacles is an additional way to improve the completeness and correctness of the achieved results. The modelled relations between the objects of interest in the semantic net can be exploited by regarding the similarities in geometry. For instance, field boundaries can be used to define search areas for a second extraction process of wind erosion obstacles, and wind erosion obstacles can help to define search areas for a second extraction process of field boundaries. Moreover, wind erosion obstacles may occlude field boundaries and therefore can be considered as field boundaries, although these boundaries are of course not detectable. Another possibility which may occur is the re-examination or elimination of extracted objects due to contradictory characteristics, for example intersecting geometries.

## ACKNOWLEDGEMENTS

This work is part of the GEOTECHNOLOGIEN project funded by the Federal Ministry for Education and Research (BMBF) and the German Research Council (DFG) under contract no. 03F0374A.

## REFERENCES

ALKIS (Amtliches Liegenschaftskataster-Informationssystem), 2003. http://www.lverma.nrw.de/alkis/frameALKIS.htm (accessed 25.06.2003).

ATKIS (Amtliches Topographisch-Kartographisches Informationssystem), 2003. http://www.atkis.de (accessed 25.06.2003).

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

Bordes, G., Guérin, P., Giraudon G., Maitre, H., 1996. Contribution of External Data to Aerial Image Analysis. In: *The International Archives of Photogrammetry and Remote Sensing*, Vol. 31, Part B4/IV, pp. 134-138.

Borgefors, G., Brandtberg T., Walter, F., 1999. Forest Parameter Extraction from Airborne Sensors. In: *The International Archives of Photogrammetry and Remote Sensing*, Vol. 32, Part 3-2W5, Automatic Extraction of GIS Objects from Digital Imagery, Munich, 8.-10. September 1999, pp. 151-158.

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

Endrullis, M., 2000. Bundesweite Geodatenbereitstellung durch das Bundesamt für Kartographie und Geodäsie (BKG). In: R.Bill and F. Schmidt (eds.), *ATKIS – Stand und Fortführung.* Beiträge zum 51. DVW-Seminar am 25. und 26.9.2000 an der Universität Rostock, Schriftenreihe des DVW, Band 39, Verlag Konrad Witwer, pp. 39-52.

Englisch, A., Heipke, C., 1998. Erfassung und Aktualisierung topographischer Geo-Daten mit Hilfe analoger und digitaler Luftbilder. PFG 3, pp. 133-149.

Förstner, W., Liedke, C.-E., Bückner, J. (eds.), 1999. Workshop on *"Semantic Modeling for the Acquisition of Topographic Information from Images and Maps" (SMATI `99)*, 07. Sept. 1999, Munich.

Grenzdörffer, G., 2002. Konzeption, Entwicklung und Erprobung eines digitalen integrierten flugzeuggetragenen Fernerkundungssystems für Precision Farming (PFIFF). Dissertation, DGK Reihe C, No. 552.

Heipke, C., Pakzad, K., Straub, B.-M., 2000. Image Analysis for GIS Data Acquisition. Photogrammetric Record, 16(96), pp. 963-985.

Koch, H., Pakzad, K., Tönjes, R., 1997. Knowledge Based Interpretation of Aerial Images and Maps Using a Digital Landscape Model as Partial Interpretation. Workshop on *"Semantic Modeling of Topographic Information from Images and Maps" (SMATI `97)*, 21.-23. May 1997, Bonn, pp. 3-19.

Löcherbach, T., 1998. Fusing Raster- and Vector-Data with Applications to Land-Use Mapping. Inaugural-Dissertation der Hohen Landwirtschaftlichen Fakultät der Universität Bonn.

Mayer, H., 1998. Automatische Objektextraktion aus digitalen Luftbildern. Habilitationsschrift, DGK Reihe C, No. 494.

NLFB (Niedersächsisches Landesamt für Bodenforschung), 2003. http://www.nlfb.de (accessed 25.06.2003).

Straub, B.-M., Heipke, C., 2001. Automatic Extraction of Trees for 3D-City Models from Images and Height Data. In: Baltsavias, E., Gruen, L., van Gool, L. (eds.), *Automatic Extraction of Man-Made Objects from Aerial and Space Images (III)*, A.A. Balkema Publishers, pp. 267-277.

Thiermann, A., Sbresny, J., Schäfer, W., 2002. GIS in WEELS. GeoInformatics, Vol. 5, pp. 30-33.

Tönjes, R., 1999. Wissensbasierte Interpretation und 3D-Rekonstruktion von Landschaftsszenen aus Luftbildern. Dissertation, Fortschritt-Berichte VDI, Reihe 10, Nr. 575, VDI-Verlag.