AUTOMATIC VERIFIACTION OF AGRICULTURAL AREAS USING IKONOS SATELLITE IMAGES

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ABSTRACT:

The usefulness and acceptance of geoinformation systems (GIS) mainly depend on the quality of the underlying geodata. The aim of this paper is to introduce an approach for the verification of cropland and grassland objects in a GIS. The approach compares the GIS objects with data derived from high resolution remote sensing imagery using image analysis techniques. Textural, structural, and radiometric features are assessed in order to check whether a cropland or grassland object in the GIS is correct or not. The approach is presented in detail, and examples are given for various stages of the method. Both the potential and the limitations of the system are also discussed.

1. INTRODUCTION

As a consequence of the wide-spread application of digital geo-data in GeoInformation Systems (GIS), quality control has become increasingly important. A high degree of automation is required in order to make quality control efficient enough for practical application. This goal can be achieved by automatic image analysis techniques. An example for how this can be achieved in the context of quality control of GIS objects corresponding to cropland and grassland is given in this paper.

The basic methodology to represent the real world in a geoinformation system (GIS) is to define objects using a data model (e.g. a feature type catalogue) which defines objects to be contained, as well as their properties and structure. In DIN EN ISO 8402 (1995) *Quality* is defined as the "Totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs". Hence, firstly the data model must represent the real world with sufficient detail and without any contradictions (quality of the model). Secondly, the data must conform to their specification (quality of the data). This paper will focus on the quality of the data, especially the verification as a part of quality management and as a basis for updates. There are four important quality measures for the quality control of geodata: *consistency*, *completeness*, *correctness*, and *accuracy*. Only the consistency can be checked without any comparison of the data to the real world. All the other quality measures can be derived by comparing the GIS data to the real world as it is represented in remotely sensed data, specifically in aerial or satellite images. This paper is focused on the quality measures that can be derived from 1 m pan-sharpened multispectral IKONOS images. These images are used to check the quality of cropland and grassland objects in the German Authoritative Topographic Cartographic Information System (Amtlich-topographisch-kartographisches Informationssystem; ATKIS). In Section 2, related work is presented. Afterwards, our approach is introduced in Section 3. First results are presented in Section 4. The paper concludes with a discussion about the potential and the limits of this approach.

2. RELATED WORK

In this section we briefly review approaches for extracting different vegetation types based on textural, radiometric and structural features using high resolution imagery. Papers dealing with the extraction of agricultural areas by means of structural features are mostly focused on the extraction of vineyards, orchards, or plantations. However, the structural characteristics exploited for the extraction of these objects also occur in cropland, namely straight parallel lines. In the case of cropland, these lines are visible structures caused by tilling. The spectrum of the techniques used in this context is wide and includes Hough (Ruiz et al., 2007), Fourier (Chanussot et al., 2005; Ruiz et al., 2007 and Wassenaar et al., 2002) and Radon transforms (Chanussot et al., 2005), Gabor filtering (Delenne et al., 2008), variograms (Trias-Sanz, 2006 and Ruiz et al., 2007), and autocorrelation (Warner and Steinmaus, 2005).

Autocorrelation is used by Warner and Steinmaus (2005), who identify orchards and vineyards in IKONOS panchromatic imagery. After the definition of a square kernel and the radiometric normalization of each pixel of this kernel the autocorrelation for the cardinal directions and both diagonals is determined, which results in one autocorrelogram per direction. An orchard pixel is detected if an orchard pattern is identified in more than one autocorrelogram centred on that pixel. For this method to work, the rows of plants have to be approximately equally spaced. A similar assumption is made in (Chanussot et al., 2005), who estimate the orientation of vineyard rows automatically from aerial images by using the Fourier spectrum of a pre-processed image and its Radon transform. This assumption is usually satisfied for vineyards, but not necessarily for cropland. In cropland the distance between furrows can vary from one field to the next, depending on the type of crop planted in the field, on the kind of machine used for tilling, and on the visibility of the structures in the image of one field.

Another method for the classification of various types of vegetation distinguished by their spatial patterns in aerial images is presented by Delenne et al. (2008). They use a frequency analysis to estimate the row width and orientation and to detect the boundaries of vineyards. After preprocessing, which includes the calculation of the Normalised Difference Vegetation Index (NDVI) and a normalization of the images, Gabor filtering is used to detect the orientation parameters iteratively. Limitations of this approach are that the number of iterations is not predictable, the image size is limited to

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500 x 500 pixels (tiling is necessary). The method only gives reliable results for fields larger than 200 m^2. As mentioned above, the assumption of approximately equally spaced rows is usually satisfied for vineyards, but not necessarily for cropland.

The idea to use structural features is also pursued in (Trias-Sanz, 2006), who uses structural properties to discriminate objects with similar radiometric and textural properties (e.g. forest and plantation). These object classes can be distinguished only by orientation characteristics. For instance, forest and untilled fields have no main structure direction, whereas tilled fields have one, and orchards and vineyard have two. All computations are carried out within a pre-selected window called texton, whose shape and size can be arbitrary. The starting point is the calculation of a variogram, which is similar to autocorrelation. After the transformation of the variogram into a parameter space similar to a Hough space, a histogram which shows the occurrence of a direction in this space is derived. The maximum of this histogram corresponds to the primary direction in image space. A disadvantage of this approach is that the appearance of the structural features such as cultivation structures and field crop has to be homogeneous. Therefore, LeBris and Boldo (2007) first use a segmentation to extract homogenous regions before applying the algorithm of Trias-Sanz (2006). However, the approach of Trias-Sanz (2006) can be used to discriminate a large number of object classes by properly choosing the texton, but can give wrong results if the texton parameters are selected inappropriately. In contrast, we focus on the discrimination of only two object classes using structural information (grassland and cropland).

Ruiz et al. (2007) carry out a combined analysis of a semi-variogram, a Hough transformation, a histogram of distances, and a Fourier transformation to detect olive trees, citrus orchards, forest and shrubs using images of 0.50 m spatial resolution. As with (Trias-Sanz, 2006), the result of the semi-variogram strongly depends on the choice of the texton. In addition, spectral and textural features are used for the final assessment. The spectral features mainly consist of the mean value of the near infrared (NIR) channel, the NDVI, and their standard deviations; textural features are determined from the grey level co-occurrence matrix. The final decision is based on a decision tree. Results are presented for a test site in Spain.

Prior knowledge in the form of a GIS is combined with a digital terrain model (DTM) and images with a spatial resolution of 0.25 m by Wassenaar et al. (2002), who detect orchards and different kinds of vineyards (Wire-trained and Goblet) using a Fast Fourier Transformation. Due to specific knowledge about the distances between vine rows the space in the Fourier space can be reduced to find the unknown parameters. However, the variations in cropland are too wide to make similar assumptions about the spacing of the individual rows.

The distances between vine plants and the distances between the rows were also considered to be known by Hall et al. (2003), who also work with a spatial resolution of 0.25 m. First, spectral information, namely the NDVI, is used to separate plants and bare soil. Afterwards, the orientation of the rows is calculated. It has to be noted that a differentiation between plants and soil in cropland is not possible using a spatial resolution of 1 m.

In the approaches discussed up to now, radiometric features were combined with structural features. Itzerott and Kaden (2006, 2007) only use radiometric features to discriminate various farmland types. Analysing typical crops and grassland in the German federal state of Brandenburg, they could show that grassland possesses an NDVI that is significantly greater than zero in all seasons, whereas untilled cropland has a very low NDVI which is thus significantly different from the NDVI of grassland. A differentiation between agricultural classes like grassland and cropland or forest and orchards only on the basis of structural or textural features in monotemporal imagery seems to be impossible (Trias-Sanz, 2006), (Wassenaar et al., 2002). However, textural and radiometric features can rule out specific classes in the classification process. Therefore, they give helpful hints for the classification of agriculture classes.

The literature review shows that some work on the classification of farmland types using the results of a textural analysis and structural as radiometric features has been done. Our approach differs from these approaches by the way the textural analysis is carried out and by the definition of the structural features. Furthermore, the fact that our approach is embedded in a system for the verification of GIS objects has some implications for the strategy used for classification. For instance, whereas the boundaries of the GIS object are already provided by the GIS, the class definitions allow for small objects of a different class being merged with a larger object, which has to be taken into account by the verification process. The parameters have to be adapted to the quality requirements of the GIS: an undetected false classification in the GIS is penalized higher than a correct classification erroneously highlighted as false.

3. APPROACH

3.1 Overview

The goal of our approach is the verification of cropland and grassland objects of the GIS-system ATKIS using 1 m pan-sharpened multispectral IKONOS images. The images are orthorectified before processing starts. The verification is based on the results of a textural analysis and on structural and radiometric features. These features are jointly analysed in order to achieve a final assessment of each object according whether it conforms to the definition of its class in ATKIS or not. .

In this context, the different feature types distinguish different classes of objects. The textural features used by our approach can be used to separate a combined class ‘agriculture’, which comprises both cropland and grassland objects, from other classes such as ‘settlement’ or ‘forest’. A differentiation between grassland and cropland using the textural analysis is not possible due to the similar texture characteristic of these classes. On the other hand, the structural and radiometric features are used to distinguish only between cropland and grassland. Figure 1 shows our model for the classification of agricultural objects as a semantic network (Pakzad, 2001). The first level of the model describes the class agriculture in the *Real World* which can contain cropland and grassland objects. Cropland in turn may be tilled or untilled, with important implications for the appearance of such an object in the data. The second level, *Geometry/Material,* describes the geometrical and radiometric characteristics of the objects. Finally, the *Imagery* level describes how these characteristics translate into the appearance of the objects in the image. The structural analysis looks for evidence in the form of parallel lines in the image, whereas the radiometric analysis uses the NDVI.

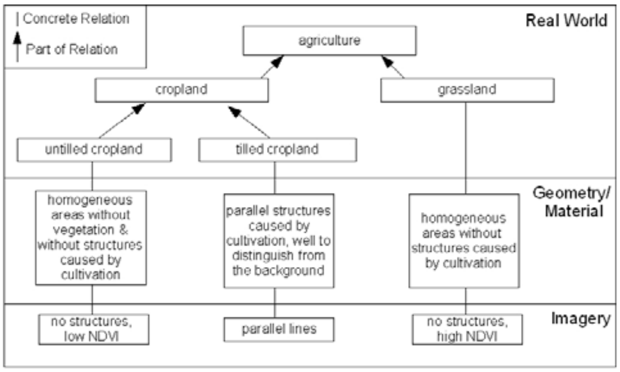

Figure 1. Model for the discrimination of cropland and grassland.

The work flow for our method starts with the definition of training areas for classes such as ‘agriculture’, ‘settlement’, or ‘forest’. Based on these training areas, a classification of the whole image based on a textural analysis is carried out. This classification is carried out for the whole scene before the actual verification procedure starts. The verification process itself is carried out separately for each agricultural object in ATKIS, i.e. for each object classified either as ‘cropland’ or as ‘grassland’. The classification results obtained for the whole scene will be accessed in the verification process of each individual object.

In the process of the verification of an individual object, the object’s boundary polygon is used to limit the analysis to areas inside the object. After that, the object has to be split into homogeneous areas by a segmentation procedure. These homogeneous areas are considered to be units having the same land use, and they are classified separately based on the results of the textural classification and on structural and radiometric features. In this procedure, the segment can be assigned to the classes ‘cropland’, ‘grassland’, or ‘other’. Finally, the whole agricultural object is assessed by merging the results of the individual classification results of all of its units. This overall assessment has to take into account the sizes of the individual segments. It is not necessary that each of the segments belongs to the class of the whole object. For instance, the definition of class ‘cropland’ in ATKIS allows for small ‘grassland’ units being merged with a larger cropland object (Adv, 2009).

Our approach is still work in progress. It is implemented in the knowledge-based image interpretation system GeoAIDA (Bückner et al, 2002). Its main components and their current implementation state are described in the subsequent sections.

3.2 Methods

3.2.1 Textural Analysis: The textural analysis is done using a supervised classification algorithm based on Markov random fields in combination with Gibbs potentials (Gimel’farb, 1996). It has been extended to simultaneously handle textures at different scales. By using manually created trainings regions the optimal Gibbs-potentials are learnt by applying a maximum likelihood estimation. Then, the classification and labelling of the image consist in finding piecewise homogenous regions using a maximum a posteriori (MAP) criterion. Simulated annealing is used to determine the class of maximum probability (Gimel’farb, 1996).

For the classification process, the algorithm needs to learn the properties of the classes from training regions. The classes to be discerned in this context depend on the scene which is to be processed. Characteristic classes for a rural area are ‘agriculture’, ‘settlement’ and ‘forest’. It is not necessary to train the operator for each image, because the trained parameters can be applied to an entire set of images having similar properties. This step is assisted by a human operator, who manually defines and classifies training regions for the desired classes. The results of the training are used during the classification process.

Busch et al. (2004) have shown that this algorithm is suitable for the classification of high resolution satellite orthophotos (IKONOS). However, the classes of interest for our approach, cropland and grassland, cannot be distinguished, because they have similar texture. Thus, we determine a combined class called ‘agriculture’ and use other features to further distinguish cropland and grassland. The classification has been shown to give best results if the near infrared, red, and green bands of a multispectral image are used.

3.2.2 Segmentation: Segmentation is necessary due to the fact that in ATKIS one agricultural object may consist of different units. For instance, a cropland object may consist of fields covered by different crops. The generalisation of ATKIS cropland objects even allows that within such an object, there may be small areas having another land use as long as they do not exceeded a certain size. For instance, there may be a small patch of grassland within a larger cropland object. This results in several problems for the structural verification of cropland objects. Firstly, different fields belonging to the same GIS object may show different tilling directions. Secondly, the borders between the individual fields may interfere with the tilling structures. Thirdly, small objects of another class may have completely different radiometric and structural characteristics. This is why segmentation is necessary to subdivide the original GIS objects into radiometrically homogeneous regions (sub-objects).

The algorithm starts with a watershed segmentation (Gonzalez and Woods, 2002) that achieves a strong over-segmentation of the image. For the merging process a *Region Adjacency Graph (RAG)* is generated; the nodes of the RAG are the homogeneous segments whereas its edges represent the neighbourhood relations. When the RAG is constructed, the attributes of both its nodes (the segments) and its edges are determined. The geometric attributes of a segment comprise its area and its centre of gravity, whereas its radiometric attributes consist of the mean grey level vector, the covariance matrix of the grey levels, and an overall measure of the noise level inside the segment. The only attribute of an edge in the RAG is the edge’s strength that measures the degree to which the boundary between the two neighbouring segments corresponds to a grey level edge or not.

The goal of the segmentation process is to merge regions that have similar radiometric properties and noise levels, but that are not separated by a significant edge. Hence, we use three criteria for merging similar segments. Two adjacent regions are merged, if the two mean grey level vectors are similar (more specifically: the difference between the two grey level vectors is statistically significant given the grey level covariance matrices), if the level of noise of the segments is similar, and if there is no significant grey level edge between the segments. If all criteria are fulfilled, these segments are merged, including the boundary pixels that formerly separated them, and the RAG is updated. This analysis is repeated iteratively until no more segments can be merged. The merging order is given by the degree of similarity between the mean grey level vectors. The algorithm is outlined in Figure 2. More details can be found in (Helmholz et al., 2008).

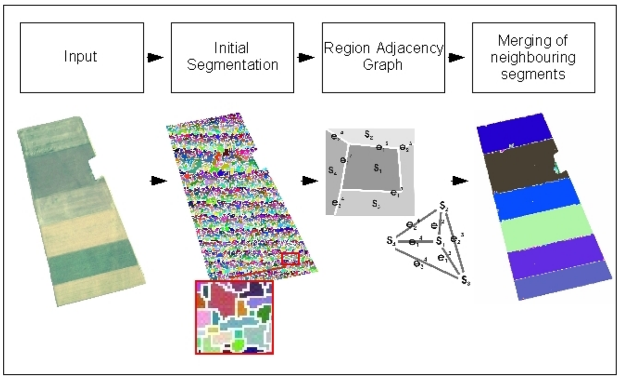

Figure 2. Segmentation of objects into radiometrically homogeneous regions.

3.2.3 Structural Analysis: The goal of this step is the differentiation of cropland and grassland in the segments of the ATKIS objects in the agriculture class using characteristic structural information. A main differentiation between grassland and cropland is the exploitation of structures caused by the cultivation, which is conducted more frequently in crop fields, compared to grassland. The agricultural machines normally cause parallel straight lines which are observable in the image.

Our approach for the detection of parallel straight lines is divided into three steps: we detect edges using the Canny operator (Canny, 1986) which then are transformed into Hough space, and finally the orientation is estimated. An overview is given in Figure 3.

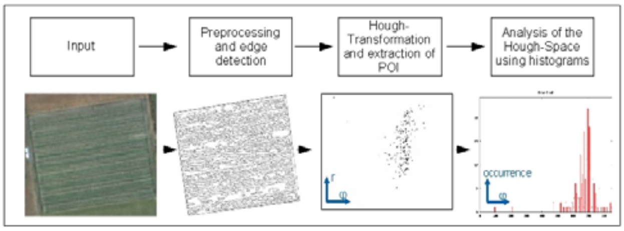

Figure 3. Steps of the structural analysis.

The edge image is transformed into a parameter space (Hough space), where an accumulator is defined. The line parameters in image space are the angle ϕ between the normal vector of the line and the x-axis and the distance r of the line from the origin. These parameters define the Hough space. Thus, parallel lines are mapped into points vertically above each other, assuming the parameter ϕ is mapped to the horizontal axis in Hough space. By extracting these points of interest (POI in Figure 3) in Hough space we focus on salient lines in image space.

In the next step, a histogram of the extracted points along the ϕ–axis in Hough space is derived. A Gaussian curve is to the histogram, and the resulting standard derivation σ is checked. For cropland, we assume parallel straight lines caused by tilling. That is, the standard deviation σ of the orientation angles must be low. It thus is compared to a pre-defined threshold σ_{max}. If $\sigma > \sigma_{max}$, the segment is assumed to correspond to grassland.

This procedure fails if line structures caused by cultivation are not observable (e.g. maize close to harvest, untilled crop fields), if lines in crop fields are not straight respectively parallel to each other (e.g. on hillsides), if grassland possesses parallel lines (e.g.mowed grassland), and at a specific point in time when the crop looks like green grass and structures are not visible. The first three problems may be corrected by radiometric features, though the differentiation between cropland and mowed grass may be difficult if the mowed grass (which is no longer vivid) covers the ground so densely that its spectral signature is close to bare soil. The time when the crop looks like grass (shortly after gestation) has to be avoided.

3.2.4 Radiometric Analysis: As stated above it is sometimes impossible to differentiate between cropland and grassland solely by means of structural features. For instance, untilled cropland shows no structural features in the image resolution we are dealing with (1 m). The verification method used in our work is to be expanded by using the NDVI: untilled cropland has a low NDVI, whereas the NDVI of grassland and tilled cropland is usually rather high (Itzerott & Kaden, 2006, 2007). Therefore, if we detect no vegetation, grassland can be ruled out. An example is given in Figure 4 where the range of the NDVI was scaled to the interval [0,255].

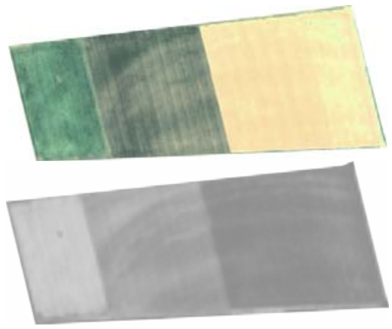

Figure 4. RGB-image (top) and NDVI-images (below) of a tilled cropland field (left), an untilled cropland field (middle) and a field with dead vegetation (right)

There are different ways to use the NDVI for differentiating cropland and grassland. If no prior information about the NDVI is available, supervised training can be applied. In a given scene, sample areas of cropland and grassland have to be selected, and the mean value and the standard deviation of the NDVI for both classes has to be computed from these regions. If the mean values are significantly different from each other, the NDVI can be used for the segmentation. Otherwise, the classes are not separable using the NDVI.

If prior knowledge is available, it is possible to differentiate the tow classes using an unsupervised classification. Prior knowledge is the date and time when the image was taken, and NDVI tables such as those published in (Itzerott and Kaden, 2006, 2007). The advantage of such an approach is that no training is required, but on the other hand, it may be sensitive to variations in the growing period. Detailed studies have to be carried out in the future.

3.3 Classification

As pointed out in Section 3.1, there are two assessments that have to be carried out in order to verify an agricultural object in ATKIS. First, each of the segments representing a unit of the object has to be classified, and secondly, the classification results of the individual segments have to be combined for the verification of the whole object

3.3.1 Classification of the segments: The classification of a segment is done by combining the results of the textural, radiometric and structural analysis for this individual segment. The classification is based on a hierarchical set of rules that are applied to the segment. Firstly, if the majority of the pixels belonging to a segment were assigned to another class than 'agricultural' in the textural analysis or if the segment contains at least one larger contiguous group of pixels assigned to another class, the segment is classified as being neither cropland nor grassland (class 'other'). If a segment has been found to correspond to the 'agricultural' class, the structural analysis is used to determine whether the segment has a dominant tilling direction. In this case, the segment is assigned to the class 'cropland'. Otherwise, the NDVI is used to differentiate between 'cropland' and 'grassland'. As an alternative to such a rule-based technique, other methods that simultaneously evaluate the evidence provided by the features will be investigated in the future.

3.3.2 Assessment of the object: The classification of the object is done by merging the results of the classification of all segments of this object where we have to take into account special characteristics of the used GIS ATKIS which were described before in section 3.2.2. (segmentation). The specifications can be implemented using an evaluation catalogue that was designed by use of the ATKIS catalogue and with use of the experience of human operators. Therefore, the final classification decision is based on the definition in the ATKIS objects catalogue.

4. EXAMPLES

In this section, we want to present examples for the algorithms implemented so far. Note that the radiometric analysis is still work in progress. The examples are presented for two IKONOS scenes. The first scene was acquired on June-18, 2005 in the area of Halberstadt, Germany (Figure 5). The second scene was acquired on June-24, 2003 in the area of Weiterstadt, Germany (Figure 6). Firstly, texture analysis was applied on the entire images using the classification classes 'agricultural', 'settlement' and 'forest'. The results for Halberstadt and Weiterstadt are shown in Figures 7 and 8, respectively.

For the presentation of the results of the segmentation and structural analysis we will focus on the objects highlighted in cyan in Figure 5 and 6. Figure 9 shows the segmentation results superimposed to the image (left), and the structural analysis of each segment (right) for the object in Halberstadt. Figure 10 shows the image (left), the segmentation results (centre), and the structural analysis (left) for the object in Weiterstadt. In both cases, all segments were classified as 'agricultural' by the textural analysis. In Halberstadt (Figure 9), the two main segments correspond to the two management units, and both were classified as cropland by the structural analysis. Therefore, the entire object was verified as a cropland object. In Weiterstadt, two of the management units were merged (blue segment in Figure 10), but all the others were correctly separated. In any case, the structural analysis could classify all segments as cropland, so that the entire was verified as a cropland object.

Figure 5. RGB-IKONOS image from Halberstadt with ATKIS superimposed to it (red: settlement, green: cropland, blue: grassland, yellow: forest).

Figure 6. RGB-IKONOS image Weiterstadt with ATKIS superimposed to it (red: settlement, green: cropland, blue: grassland, yellow: forest).

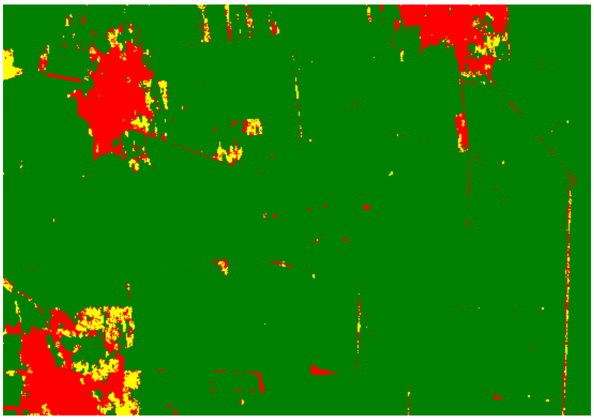

Figure 7. Results of the textural analysis for Halberstadt (green: agricultural, red: settlement, yellow: forest).

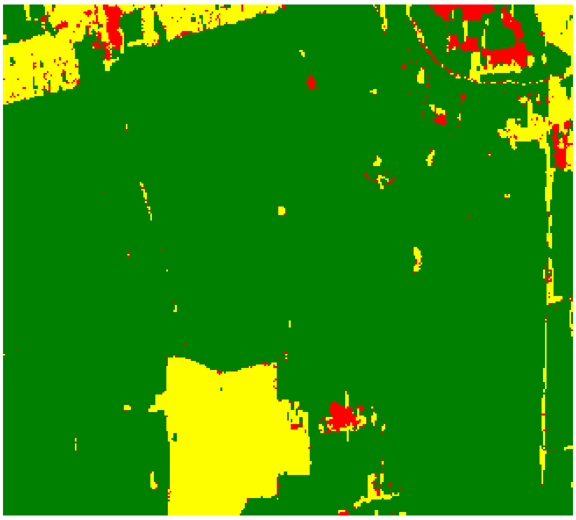

Figure 8. Results of the textural analysis for Weiterstadt (green: agricultural, red: settlement, yellow: forest).

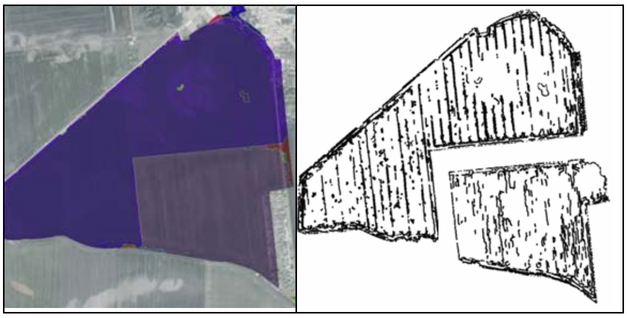

Figure 9: Cropland object with segmentation result (left) and the result of the structural analysis (right).

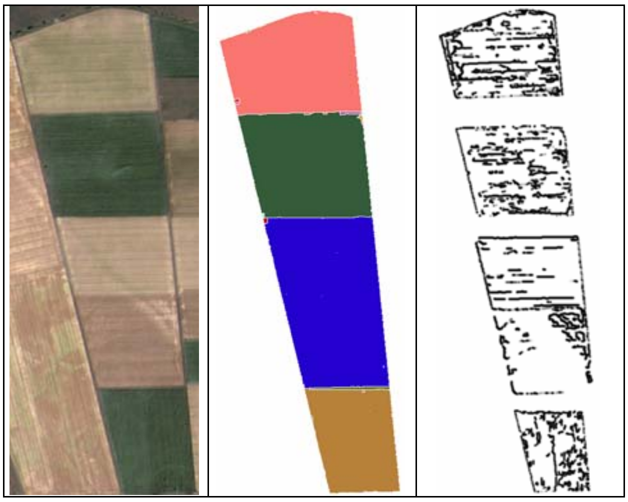

Figure 10: Cropland object with segmentation result (left) and the result of the structural analysis (right)

5. CONCLUSIONS AND OUTLOOK

In this paper, a method for the verification of cropland and grassland objects in a GIS has been presented. Each GIS object is verified individually, taking into account the results of a texture-based classification as well as structural and radiometric features. For the structural analysis to work, but also due to the class definitions used by the GIS, the object has to be segmented into homogeneous segments first. Each segment is classified individually, and the classification results for the individual segments are combined for the overall verification of the object. Currently, a rule-based algorithm is used for classification, but in the future other classification methods that evaluate all features simultaneously will be investigated. The presented method is still work in progress, because the radiometric analysis has not been implemented so far. The examples presented in this paper still show the potential of this approach, but an extensive evaluation still remains to be done.

We will also have to investigate whether the introduced approach is also suitable for an update of the GIS. In this context, the method would also have to detect new cropland or grassland objects, not only check the classification of such an object in the GIS. The detection of new objects works in a similar way as the verification of existing ones. The only difference is that, rather than existing GIS objects, contiguous segments of 'agricultural' objects extracted in the textural analysis would have to be used as candidate regions to be verified using structural and radiometric features.

We also hope to be able to detect other object classes with similar features such as vineyards and plantations. However, in this case, the image resolution would have to be adapted for the structural analysis, because the rows of plants only appear as parallel lines at a coarser resolution than 1 m. This future research would also have to determine the optimal scale for each object class.

Furthermore, there is still room for improvement of the individual components of the approach, for instance the analysis of the histogram in the structural analysis or the automatic training of the parameters for the segmentation.

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