KNOWLEDGE BASED MULTITEMPORAL INTERPRETATION

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ABSTRACT:

This paper describes a procedure for an automatic multitemporal interpretation of vegetation areas, which uses both structural features and temporal knowledge. For the interpretation of vegetation areas the concept of manual interpretation by using interpretation keys was transformed into the automatic interpretation system. For interpretation of temporal changes an approach was used, which discretely describes temporal conditions of regions, and which transfers the most probable temporal changes of the given conditions as temporal knowledge into a state transition diagram, then using it for multitemporal interpretation. Based on these approaches a procedure for automatic multitemporal interpretation of industrially used moorland was successfully developed. Proceeding from an initial segmentation based on Geo-Data a resegmentation and an interpretation of the segments is carried out for each investigated epoch. By using temporal knowledge it is possible to separate moor classes, which can only be detected in temporal order. The application of temporal knowledge and structural features enables the exclusive use of grey scale images for interpretation of vegetation areas. The results show that the presented procedure is suitable for multitemporal interpretation of moorland, and that it is able to distinguish additional moor classes compared to the approaches used so far. It is further applicable for a more robust multitemporal interpretation, and does not depend on colour images.

1. INTRODUCTION

The method, which has to be used for the interpretation of an image relies on the characteristic of the objects, which can be found in the scene. Different groups of objects can be distinguished. One contains landscape objects, which can be recognized by their characteristic unequivocal shapes. To recognize them, it is necessary to search for special shapes, perhaps in conjunction with a particular radiometry and texture. However, the shape of such objects is the most important characteristic.

A second group of objects are those, which have no characteristic shape, but can also be recognized by their known roughly homogenous texture and radiometry. The landscape object forest is an example for such an object.

Many objects can be described and recognized by the composition of object parts, which can be taken from objects of the described groups, and which have particular spatial relations to each other. Many artificial landscape objects can be described in this way.

However, for interpretation of many vegetation areas the distinction from these two groups is not sufficient. Especially biotope areas hardly ever show particular shapes or a homogenous texture. Nowadays this group of objects and areas is manually interpreted. So-called interpretation keys are often used for interpretation. They describe characteristic features or structures for different objects or areas, which have to be found for assigning a special meaning to them. The interpretation keys can be divided into selection keys and elimination keys. The selection key provides several example images for every known class. Interpretation is done by comparison of the example images and the examined image parts. The elimination key systematically provides features and structures, which have to be found in the images. In a first step it describes features and

structures for the separation of coarse classes. Then the description is refined step by step for more and more classes.

The existing approaches for automatic interpretation of landscape objects primarily treat objects from the first two groups. The approaches for interpretation of objects and areas from the third group mostly use only multispectral classification methods. The result of a multispectral classification of such objects is an oversegmentation of those object areas, which would be interpreted as one area by a human operator.

The strategy used in this work is based on the described manual approach, which applies interpretation keys and finds necessary features and structures for a class. Therefore the goal was on the one hand to transform the interpretation keys, which in Germany already exist for many feature classes (e.g. Von Drachenfels, 1994), into the interpretation system and use them for the automatic interpretation, and on the other hand to do this easily.

These considerations lead to the following conditions:

1. The system must enable to save and to use explicit knowledge.
2. As the examined areas could be inhomogeneous, a multispectral classification is not suitable to find segment borders.
3. It should be possible to automatically verify the interpretation keys in the images by using image processing operators.

Condition 1 was fulfilled by using the knowledge based interpretation system AIDA (Automatic Image Data Analyser). AIDA uses an explicit knowledge representation by semantic nets. A short description will follow in section 2.

Condition 2 was considered in the strategy by separation of the recognition of segment borders and the interpretation of the particular segments. A description of the extraction of segment borders follows in section 3, and of interpretation in section 6.

To fulfil condition 3 feature analysis operators were created, which are described in section 4.

The aim of this work was to detect changes over the time. Therefore another condition is the possibility to model and use possible temporal landscape changes in the system, which is described in section 5.

2. KNOWLEDGE BASED SYSTEM

The system used for the presented approach is the knowledge based system AIDA (Liedtke et al., 1997, Tönjes, 1999) which was developed for automatic interpretation of remote sensing images. The system strictly separates the control of the image analysis process from the semantics of the scene. The knowledge representation is based on semantic nets (Niemann et al., 1990). Semantic nets are directed acyclic graphs. They consist of nodes and edges in between the nodes. The nodes represent the objects expected in the scene while the edges or links of the semantic net model the relations between these objects. Attributes define the properties and methods of nodes and edges.

The nodes of the semantic net model the objects of the scene and their representation in the image. Two classes of nodes are distinguished: the concepts are generic models of the objects and the instances are realizations of their corresponding concepts in the observed scene. Thus, the knowledge base, which is defined prior to the image analysis is composed of concepts. During the interpretation a symbolic scene description is generated consisting of instances.

The relations between the objects are described by edges or links of the semantic net. The specialization of objects is described by the is-a relation introducing the property of inheritance. Along the is-a link the description of the parent concept is inherited to the more special node which can be locally overwritten. Objects are composed of parts represented by the part-of link. Thus, the detection of an object can be simplified to the detection of its parts. The transformation of an abstract description into its more concrete representation in the data is modelled by the concrete-of relation, abbreviated con-of. This relation allows for structuring the knowledge in different conceptual layers, for example a scene layer and an image layer.

To make use of the knowledge represented in the semantic net control knowledge is required, which states how and in which order the image interpretation has to proceed. The control knowledge is represented explicitly by a set of rules. The rule for instantiation for example changes the state of an instance from hypothesis to complete instance, if all subnodes, which are defined as obligatory in the concept net have been completely instantiated. If an obligatory subnode could not be detected, the parent node becomes a missing instance. The control of interpretation is also performed by an A*-Algorithm. For further details see (Tönjes, 1999).

3. EXTRACTION OF SEGMENT BORDERS

As described above a separation between the extraction of segment borders and the interpretation of segments was carried out. Extraction of the segment borders was the first step for every epoch of the multitemporal interpretation, then the interpretation was done. The border extraction for the first epoch, in the following called initial segmentation, differs from the others, called resegmentation.

Investigating the position of segment borders in manually created vegetation and biotope mappings shows that landscape objects were often used as borders. This applies also for industrially used moorland, which was investigated in this work. Suited as a border are streets and paths, waters and ditches. These objects can be extracted by existing methods (an overview of different approaches is given in (Förstner, 1999, Mayer, 1998)) and used directly as borders. As researches in this area were not part of this work, existing Geo-Data were used directly as segment borders. Thus, in a first step the first segments were created. This step is only carried out for the first epoch.

In a second step, which is used for all epochs, these segments were processed. In each segment parts are selected during processing. The selection criteria depend on the kind of input images: Greyscale or CIR(Colorinfrared)-Images. For CIR-Images all parts without vegetation (low NDVI-Value) are selected, and for greyscale images all parts without textures with parallel lines. Then the selected parts are processed by morphological operations. Finally it is decided if the segment splits into the processed parts or not. This depends on several criteria:

- They must have a particular relative and absolute minimum size.
- A part of the new segment border must match the old border.
- The shape has to fulfil specific conditions.
- Further criteria.

Greyscale and colour-images are handled differently. The higher uncertainty of greyscale images (because of the missing colour information) leads to stricter criteria for the acceptance of new segments.

The described resegmentation is carried out for every segment found during the initial segmentation. Resegmentation for the next epochs will only be performed considering particular conditions and only for segments, which were assigned to special classes. This means, that resegmentation is only necessary for particular classes. This reduces the error of resegmentation.

4. RECOGNITION OF CHARACTERISTIC STRUCTURES

The interpretation keys, as explained in section 1, describe features and structures, which have to be recognized. To implement this concept into an automatic interpretation system the interpretation keys must be implemented as image processing operators. Automatic recognition of features and structures is done by automatic feature analysis operators.

The input of a feature analysis operator is a segment, which has to be examined for special features and structures. Also, additional parameters of the kind of the structures and of the resolution of the images are given to the operators. After verification the operator's result is a value between 0 and 1, which describes the number of examined features in the given segment.

Transformation of indistinct descriptions, which are given in standard language, as for example "dismembered structure", into image processing operators is difficult. For example, the operator for "dismembered structure" has to fulfil the following conditions:

1. The edges of the image structures have to be curved.
2. Higher density of curved structures should lead to better results.
3. The spatial distribution of the curved structures should be equal all over the segment.
4. Uncurved structures should not influence the result of the operator.

With these conditions a feature analysis operator was created. The sensitivity and the point, from which the operator shows a positive reaction, were calibrated by human operators by using test textures. For every such texture they decided on the operator's reaction. Using these data the operators were calibrated.

Table 1 shows exemplary results of the verification of three textures with the three image processing operators "parallel lines", "dismembered structure" and "preferred direction". The operator for "parallel lines" shows a positive reaction for texture 1 and a negative reaction for texture 3. The operator "dismembered structure" shows positive reaction for texture 2 and negative for texture 1. The third operator "preferred direction" found this feature in textures 1 and 3, but only a small quantity in texture 2. These results correspond to the results of human operators.
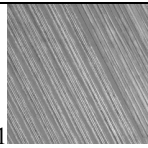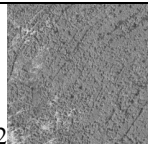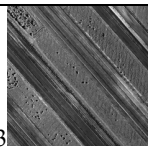
Operator Texture	Parallel Lines	Dismembered Structure	Preferred Direction
1	1,00	0,01	1,00
2	0,34	1,00	0,26
3	0,69	0,16	0,90

Table 1. Reaction of some operators for different textures

5. STRATEGY OF MULTITEMPORAL INTERPRETATION

Literature discusses different approaches for multitemporal interpretation of remote sensing data (Lunetta & Elvidge, 1999). The first group of approaches is known as pixel-wise comparison. These approaches compare pixels of different epochs (e.g. Peled et. al., 1998). One possible way is to subtract the grey values of the pixel, thus detecting changes. Also, different vectors can be subtracted, based on multispectral images. The disadvantage of these approaches is the necessity of precise spatial rectification.

The second group of approaches are known as postclassification approaches. These approaches start with a separate multispectral classification of the images of every epoch (e.g. Weismiller et. al., 1977). Then the classification results of the different epochs are compared to each other. Here it is of disadvantage that these approaches depend on the classification methods. It is difficult to decide whether the differences between the classifications of the various epochs result from inaccuracies of the classification method or from real changes in the scene. These approaches also need precise spatial rectification.

The third group of approaches compares the images of different epochs on the semantic level. Different conditions are formulated for the possible changes of different objects from

one epoch to another. Therefore, the objects in the scene are interpreted by using the knowledge of possible temporal changes. The approach used in this work is assigned to this group.

The approach discretely describes temporal conditions of regions, and it transfers the most probable temporal changes of the given conditions as temporal knowledge into a state transition diagram. This is used for multitemporal interpretation, which means, that the temporal part of the prior knowledge is implemented into a state transition diagram. Figure 1 shows the state transition diagram, which in this approach was used for the interpretation of industrially used moorland.
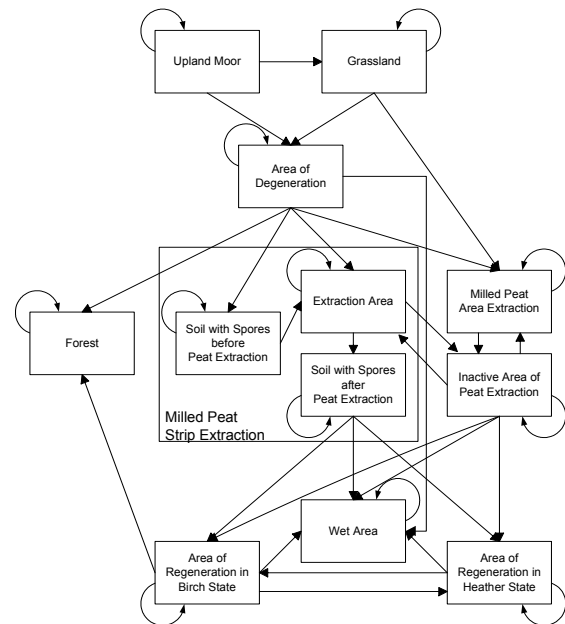

Figure 1. State Transition Diagram

Although many more state transitions are theoretically possible, there are restrictions by law and by nature, and we can use these restrictions to improve the interpretation. The state transition diagram contains twelve different states (in multitemporal context, in the following classes are also designated as states). The first state, upland moor, is implemented only to complete the diagram. Distinction of so many states is only possible by using for every segment the knowledge of temporal history. It is, for example, very difficult to distinguish the "area of degeneration" from "area of regeneration" in aerial images taken at one epoch. But this distinction is possible by using temporal knowledge. For example: If the state "area of milled peat extraction" is given, the system will know that this segment has passed the state "area of degeneration", and it will not try to find features and structures for the state "area of degeneration" for the interpretation of the next epochs. The search space as well as the possible errors will be reduced. This use of temporal knowledge also allows distinction of the two regeneration states "heather" and "birch".

Based on the concepts described above the system used was extended by temporal relations (see Growe, 2001). They realize the use of temporal knowledge. For each temporal relation a priority can be defined for sorting the possible successor states by decreasing probability. During scene analysis the state transition diagram is used for generating hypotheses for the next observation epoch. For each of these possible state transitions a hypothesis is generated. All hypotheses are treated as competing alternatives.

6. INTERPRETATION OF MOORLAND

6.1 Prior knowledge about moorland

In this section some background knowledge about industrially used moorland is given (see also Eigner & Schmatzler, 1991). Following that the implementation of that knowledge into semantic nets, the knowledge representation language of our system, is shown.
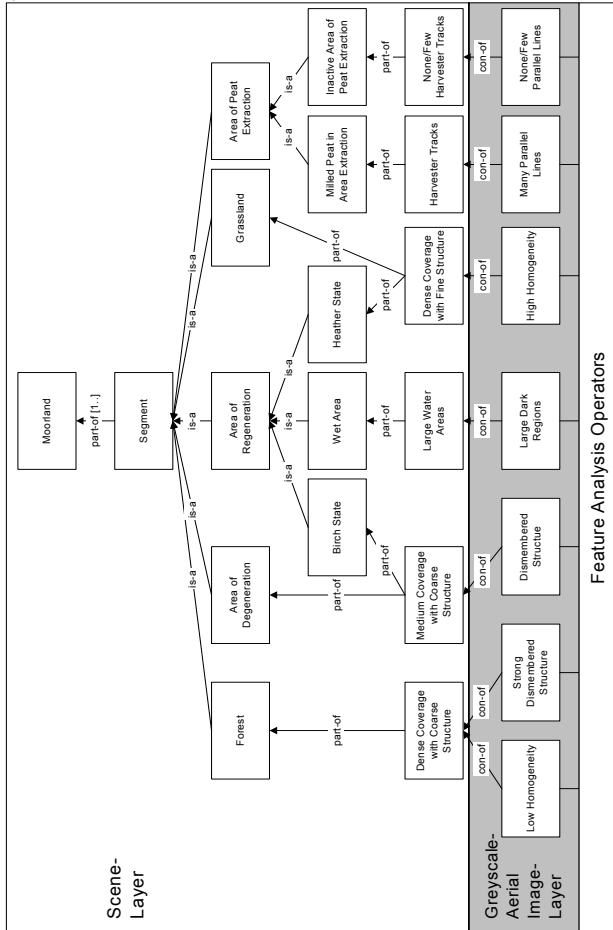

Figure 2. Semantic net for greyscale images

Originally, moors were upland moors. In Germany these have practically vanished. Today, in the former upland moors agricultural areas, forests and areas of regeneration or degeneration are found. The most important industrial use of moorland is peat extraction. To enable peat extraction in a moor the ground must be drained first. For this purpose ditches must be dug. Thus, the water level decreases, and the area begins to degenerate. The vegetation changes. During degeneration the vegetation is inhomogeneous and irregular. Then, peat extraction is possible. Usually harvester machines are used for this task. These machines leave two straight tracks on the ground, which in aerial images can be recognised as parallel lines. It is possible that peat works stop for a short time, and then continue again. After peat works have finished, regeneration of the moorland can begin. In most cases people simply stop working the land and leave it to regenerate, which eventually results in increased vegetation. Hence, vegetation can be found again on these areas, especially birches, because of the dry ground. Remains of tracks from the harvester machines may still be found. To start up regeneration in the direction of the original moorland, sometimes supporting steps

are carried out, as for example filling up of ditches, and trees are removed to raise the water level. If the water level further rises trees die, and a homogeneous vegetation without trees appears.

A representation of the temporal part of this knowledge can be seen in the state transition diagram in figure 1. The monotemporal part is represented in semantic nets. Figure 2 shows one of them, designed for the interpretation of greyscale images. At the top the moor classes are shown. Below, their obligatory parts contain the features and structures, which have to be found. The nodes in the greyscale aerial image layer describe the appearance of features and structures in the aerial images. These nodes are connected to the feature analysis operators (described in section 4).

As described below the interpretation of greyscale and colour-images needs different semantic nets. The semantic net for greyscale images is able to distinguish eight different states, and the net for CIR-images 12. This shows, that the missing colour information results in no more than 30% less classes, which can be distinguished. These numerous classes are achieved by using structural and texture information. An example for a semantic net used for CIR-images, as well as a more detailed description regarding the use of semantic nets for interpretation is described in (Pakzad, 2001, Pakzad et al. 2001, Heipke et al. 2000).

6.2 System Overview

Figure 3 shows an overview of the multitemporal interpretation system. The interpretation starts with an initial segmentation based on Geo-Data and radiometric/textural information for the images of the first epoch, as described above. This results in segment borders, which are the basis of further interpretation. An interpretation for every segment is performed inside the segment borders.
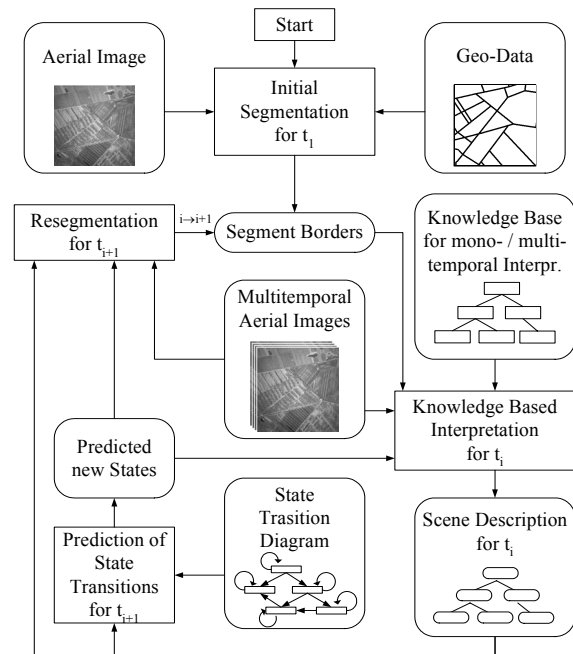

Figure 3. Multitemporal interpretation system

The interpretation procedure utilizes semantic nets as knowledge base. The semantic net, which is used for the interpretation of the first epoch differs from the semantic nets for interpretation of the next epochs. The reason is that some classes can only be recognized by using temporal history. This

history does not exist for the first epoch. Section 6.1 describes the semantic nets used.

Resulting from interpretation of the first epoch is a scene description with interpreted segments of moorland. For interpretation of the next epoch these segments are used as input for a prediction of state transitions. This prediction uses prior information concerning possible changes. The possibilities are represented in a state transition diagram (see section 5). The output of the prediction are "predicted new states" for every segment. The segment borders may change during interpretation intervals. Therefore it is necessary to perform a resegmentation of the already interpreted segments by additionally using the images of the new epoch. The resegmentation results in segments with possibly new borders, which are used for interpretation of the new epoch together with the semantic nets for multitemporal interpretation and the possible state transitions. Thus, the iteration continues for all epochs to be interpreted. For more information see (Pakzad, 2001).
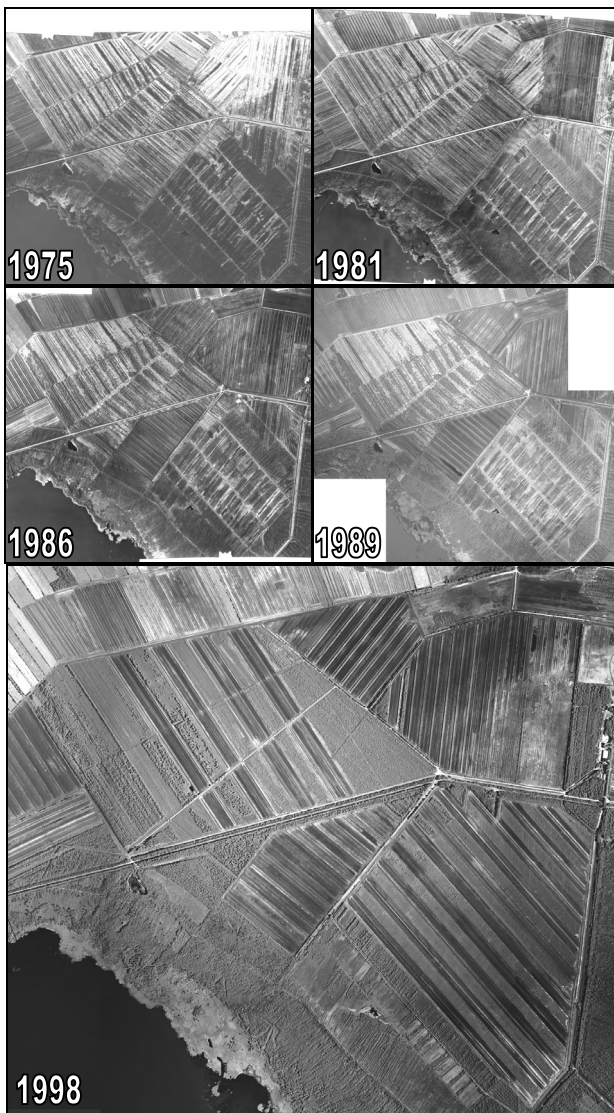
7. RESULTS

Figure 4. Aerial images from test area

Test area is the moor "Totes Moor" northwest of Hannover in Lower Saxony. The methods developed were tested for two parts of the test area. Aerial images with a resolution of 0.5m/pel from five epochs were used. For the part in figure 4 we used the epochs 1975, 1981, 1986, 1989 and 1998. The input sources of the last two epochs are CIR-images, the rest are greyscale. The reason of using greyscale images is that most available aerial images are greyscale images, despite of the better information contents of colour images. Figure 5 shows the obtained results of one part of the test area. The size of the area is 3288m x 2964m. The initial segmentation for 1975 led to 35 segments. Most of them were assigned to the class "area of degeneration". The resegmentations during the interpretation for the five epochs led to a number of 96 segments for 1998. The amount of segments, which were classified as "area of degeneration", decreased during the epochs, while other classes increased. The reason is the fact, that at the beginning of interpretation the uncertainty of the interpreted classes was high, especially as the images of the first epochs were greyscale images, and the probability for the class "area of degeneration" is higher than for the other classes.
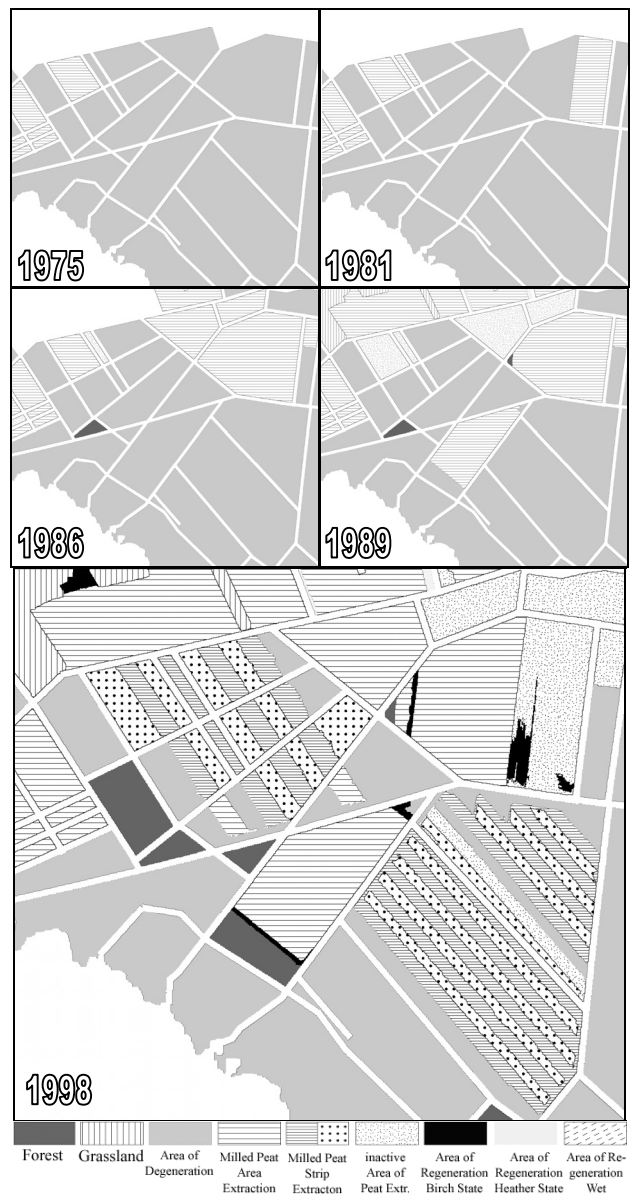

Figure 5. Results of moorland interpretation

The assessment of the results was performed by comparison of the results of the automatic interpretation, as described in this paper, and a manually created biotope mapping for the last epoch 1998. Two points were included into the comparison: the segment borders and the classification of the segments. The segment borders were in most cases similar, as well as the classes. Following differences could be found: Some areas, which were manually classified as "forest", were assigned to "area of regeneration birch state" by the automatic system. Also, the opposite case could be found. The reason is that there is no sharp separation between transition of these two classes. The question, when the class "area of regeneration birch state" ends and when the class "forest" begins is more or less subjective.

In some other areas the automatic system classified "area of regeneration" as "area of degeneration". The reason is that both classes look very similar. The assignment to one of these classes can only be done by using temporal history of the segments (see above). For the misclassified cases the automatic system did not have enough temporal information for the epochs before 1975. The use of images from epochs before 1975 would probably lead to correct results in those segments.

8. CONCLUSION

A system for knowledge based multitemporal interpretation of aerial images was presented. The explicit knowledge representation allows an easy integration of expert knowledge into the system. For interpretation of vegetation areas the concept of manual interpretation by using interpretation keys was transformed into an automatic interpretation system by using feature analysis operators. For interpretation of temporal changes an approach was presented, which discretely describes temporal conditions of regions, and which transfers the most probable temporal changes of the given conditions as temporal knowledge into a state transition diagram, then using it for multitemporal interpretation.

Based on these approaches a procedure for automatic multitemporal interpretation of industrially used moorland was successfully developed. Proceeding from an initial segmentation based on Geo-Data resegmentation and interpretation of the segments is carried out for each investigated epoch. By using temporal knowledge it is possible to separate moor classes, which can only be detected in temporal order. The application of temporal knowledge and structural features enables the exclusive use of greyscale images for interpretation of vegetation areas. The results show that the presented procedure is suitable for multitemporal interpretation of moorland, and that it is able to distinguish additional moor classes compared to the approaches used so far. It is further applicable for a more robust multitemporal interpretation, and does not depend on colour images.

In some parts this work contains potential for improvements. Although the feature analysis operators are designed to work with a minimum of parameters, their automatic adaption to the used images would improve the system's level of automation.

Further parts are resegmentation and probabilities of multitemporal interpretation. Additionally, the suitability of the used prior knowledge should be verified for other moor areas and other applications.

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