Integrated Processing of Remotely Sensed and Geographic Data for Land Inventory Purposes

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ABSTRACT

In a Geographic Information System (GIS), objects of interest are stored by their geometry and attribute values. The type of objects differs from user to user context. Different geometric representations can be used to describe the geometry: vector, raster and quadtree. Integrated processing of different geometric representations can be realized by means of an object oriented link to the different representations. Objects are more or less dynamic in time and space. The data in a GIS, therefore, need periodic updating.
Different types of uncertainty are related to the data in a GIS. The uncertainties involved can be described by the three components in the decision: $x \in S$.
Remote Sensing (RS) can be considered as a data acquisition technique for updating the object information in a GIS. The spectral reflectances, as determined with remote sensing, can be used to check and update both thematic an geometric descriptions of objects that are stored in a GIS. RS data are not object oriented; RS results in a Digital Number per pixel. Automatic interpretation of RS is therefore limited and yields data with some level of uncertainty. If RS is used for the updating of GIS, the available object information in the GIS can be used to improve the certainty of decisions being made in the processing of the RS data. This approach can be called an integrated approach. Some examples are given to illustrate the effect of an integrated approach.

INTRODUCTION

Geographic Information Systems (GIS) are more and more being used for the storage and analysis of geographic data. The user context of a GIS determines the objects of interest. At the Wageningen Agricultural University and the Winand Staring Centre land cover and land use are of great interest. In general, our objects of interest are agricultural fields, forested and (semi-) natural areas. Storage and updating of these objects is very relevant.

Remote Sensing (RS) seems to be a promising technique for (semi-) automatic updating of geographic databases, especially in the field of agriculture and forestry. RS data are considered to be in digital format; this could be satellite or airplane scanner data or scanned aerial photographs. The automatic processing of RS images differs very from the visual (interactive) interpretation of photographlike products because of the little number of interpretation elements that are (can be) taken into account. Automatic interpretation of RS images could be improved by including existing information on the objects of interest.

In the recent history of the so called 'integration of GIS and RS' much attention is given to graphical integration techniques: vector on raster superimposition with a shared coordinate system. Further integration comprises vector to raster and raster to vector conversion. We seek integration on database level with the aim to reduce uncertainty in the RS derived information. Therefore the object definition and description in a GIS, associated uncertainty and the characteristics of RS data will be described. In the end three examples will be given to illustrate the success of an integrated approach.

1. TERRAIN OBJECTS IN GIS

The description of terrain objects in GIS has three components. An object is represented by an identifier linked up with thematic data and geometric data as in Fig. 1. The objects are conceptual entities, that are meaningful in some context. Within such a context the semantics of the objects description will be defined. This concerns in general the object classification structure, i.e. set of (mutually exclusive) object classes.

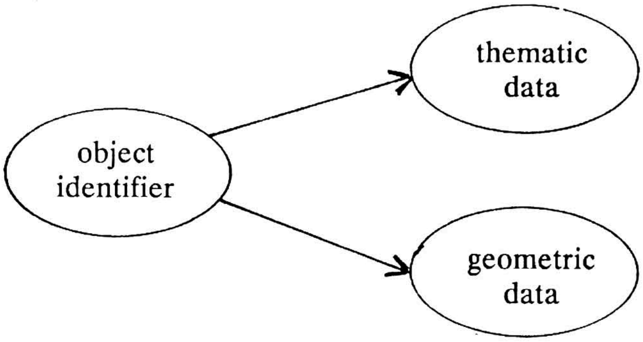

Fig. 1 - Object representation in GIS.

Fig. 2a shows that a list of attributes is connected to each class. The individual classes are identified by a label or a class name. The attribute list of a class gives the names of the attributes. The arrow in Fig. 2a indicates that in general many terrain objects belong to one class. They all have a common attribute structure, which they inherit from the class. This means that each object of the class has a list containing a value for each attribute of class attribute list. These values are taken from the value domains of individual attributes (Fig. 2b).

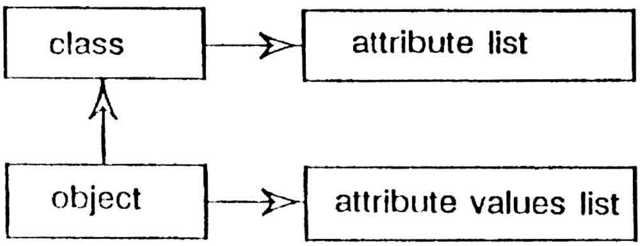

Fig. 2a - Class structure of objects.

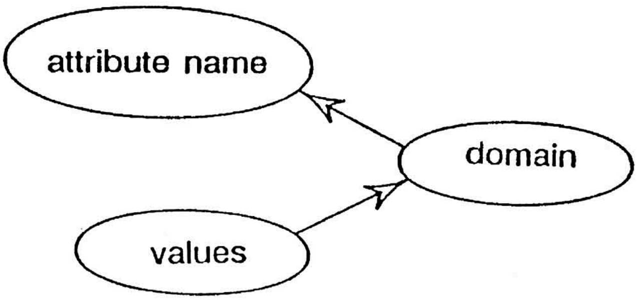

Fig. 2b - Relation: attribute - domain value.

The river Rhine is a terrain feature which belongs to the class of rivers. Relevant attributes are e.g. depth, width, maximum tonnage of a ship, maximum traffic intensity and water velocity of the current. The river Rhône can be described by the same attributes, only the values will differ.

Another semantic aspect is the geometric description of the objects. For each object a decision should be made whether it will be treated as an area object, a line object or a point object. This decision depends on the role the objects play in the analysis of spatial object relationships. A town may be treated as an area object in one context and as a point object in another. Similarly a road may be a line object in one context and an area object in another.
The terrain objects should be represented in some geometric structure such as the vector (or polygon) structure, the raster structure or a quadtree structure. A decision should be made how the three different geometric object types should be represented in these structures. See [Molenaar, 1989], [Molenaar, 1991].

For several reasons one might like to combine raster and vector data. This can be done according to two different strategies: the position oriented approach and the object oriented approach. The position oriented approach is rather simple: the data in the raster and the vector structure are combined through their common position.
This is done by transformation of the vector data into raster data with the same grid geometry as the original raster. Then the old raster and the new raster are overlayed so that the thematic data can be combined.

The object oriented approach requires that the terrain objects represented in the vector map are also represented in the raster, or quadtree map. The raster data can be transformed in the vector structure or both the vector and the raster structure are maintained and they are linked through the common object identifiers. For this last solution Fig. 2 should be modified (see Fig. 3).

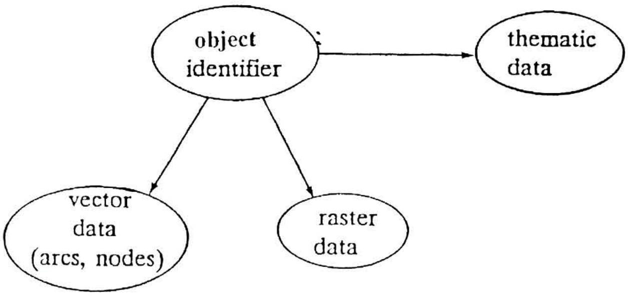

Fig. 3 - Data structure for the combination of vector and raster data.

Hence there are links between object identifiers and the raster elements for the raster representation and between the object identifiers and the geometric elements for the vector representation.

If we only consider area object, also for quadtree data, then Fig. 3 can be given in some more detail (see Fig. 4).

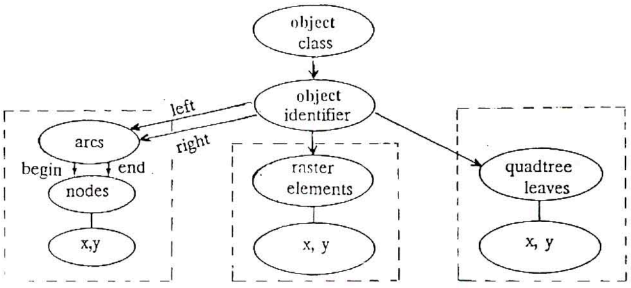

Fig. 4 - Linking object identifiers for different geometric representation.

We see that the object identifiers play a central role in the data structure. They can be linked to the different geometric representations.

2. OBJECT DYNAMICS AND REMOTE SENSING

Objects may change in time. The object dynamics can affect the object status in several ways.
Firstly the thematic data may change. In the simplest case this affects only some of the attribute values of an object, e.g. the waterdepth of a river changes, or the maximum traffic density. A more drastic change is when an object changes object class, e.g. the land use class of a field or land parcel changes from farmland to built-up area. This means that the object gets another attribute structure. All new attributes should be evaluated for the object.

Secondly the geomeric aspects of an object may change. This may also have several effects. It may be that an object only gets a new position, like a lamppost being put at another point, or like a a road being shifted. Another posibility is that an object changes shape and size like a land parcel from which a part has been split off. A third possibility is that the topological relationships among objects change, as in the case where cities grow so that they fill up the open spaces between them, or like a road being extended, so that it connects more districts or cities.

Thirdly objects may change their aggregation structure. This is the case when a farm lot is split-up in different parcels with different crop types. It may also be that several parcels are combined into one homogeneous field or that the parcel structure of the lot changes into a new set of parcels. Such dynamic behaviour occurs in farm districts if several crops are grown in one lot and if the crops rotate from year to year.

Remote sensing is in many cases a good tool for monitoring the object dynamics. To make optimal use of this tool the data contained in an RS image should be linked directly to the object information stored in a GIS. The problem is that RS data are primarily position oriented because of the image raster structure. This position oriented structure should be converted into an object oriented structure. That means that we have to identify the pixels or raster elements that are related to the terrain objects stored in a GIS. With this link Fig. 4 can be modified so that RS data can be introduced as in Fig. 5.

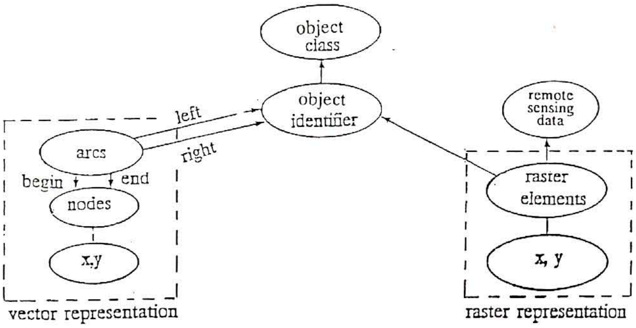

Fig. 5 - The link between object and remote sensing data.

This link can be used in two ways: Firstly the spectral date and the classification results can be linked directly to the terrain objects instead of the individual pixels. Secondly, apriori object information can be used to improve the quality of the information extraction from the RS data. The advantage of such an approach will be clear if we realise that object definitions and descriptions are always made within a certain users context. The object dynamics should also be understood within such a context. That is why the extraction of object information from RS data is seldom straight forward. E.g. different object classes often have similar or overlapping spectral signatures, additional object information may then be helpful to derive the object class from the spectral data or to derive correct values for some of the thematic attributes of the objects. Similarly object information may be helpful to detect changes in object geometry from RS data. Before explaining some strategies how to do that, we will first describe the different types of uncertainty that occur in RS data processing.

3. UNCERTAINTY

Information extracting from RS data always implies uncertainty, i.e. one can never be sure whether the results of the process are correct. There are several reasons for uncertainty. We will consider them in some more detail here.

Uncertainty is related to decisions, such as: $x \in S$, i.e. element x belongs to (sub)set S. This implies the risk that wrong decisions are made, with the consequence inadequate action follows.
This of course should be avoided, or at least the risk should be brought down to an acceptable level. Therefore we should understand the causes of uncertainty and also we should understand which are the different kinds of uncertainty. The formula "$x \in S$" has three components, uncertainty can be related to each one of them [Kliv and Folger, 1988].

Firstly the definition of a subset S may be fuzzy, in GIS this might mean that the criteria for assigning terrain objects to a certain class might be fuzzy: e.g. the definition of nature districts is not always clear. Does it mean that people do not interfere with the development of flora and fauna? Then Western Europa has no nature districts. If it means that there is only a limited interference of people, then how little should that be. No sharp criteria can be formulated. The theory of fuzzy subsets gives mathematical rules for handling this type of uncertainty. Fuzzy subsets are distinct from classical "crisp" subsets in the sense that for crisp subsets the membership function
$Ms(x) = 1$ $x \in S$ (i.e. x belongs to S) or
$Ms(x) = 0$ $x \notin S$ (i.e. x does not belong to S)
For fuzzy subsets $0 \leq Ms(x) \leq 1$, hence x may belong a little bit to S. The algebraic rules formulated in this theory are mainly of a qualitative nature, because in many practical situations it is difficult to evaluate Ms(x).

Secondly the definition of x may be uncertain. In GIS x stands for a terrain object; for which the geometry and the attribute values should be evaluated. In many cases this will be done through measuring procedures or through the processing of measuring data. Measuring operations introduce in general stochastic components in the observed data. Those stochastic components propagate through the processing steps applied to these data. The uncertainty introduced here, can then be dealt with mathematically by means of stochastic models. This means that the uncertainty can often be expressed in terms of variances and probabilities.
In remote sensing images this type of uncertainty may refer to the spatial end spectral resolution of the sensors, to the point positions and for the translation of digital numbers into intensity values or even reflectances in the different spectral bands.

Thirdly there may be no sufficient evidence to assign an element x to a subset S. This situation is different from the first case, because the criterion to assign elements to subset S might be crisp. The problem is now that it is not clear whether a particular element x fullfills the criterion or not. This case is well known in photo interpretation and remote sensing image classification. If such a classification is made to determine land cover of an area, then the land cover classes might be well defined. Still the spectral information in the image might not give sufficient evidence to assign the pixels with certainty to those classes. Similarly photo interpretation might in some cases not give enough evidence whether a particular building is a house or an office. In such situations it is this third type of uncertainty that can be reduced by using apiori object information for RS data processing. The lack of evidence in the RS data for deciding what is the status of a particular terrain object can often be compensated by the information stored in a GIS. The next chapter will give some strategies.
The subset S is crisp and the element x has been determined accurately, but still we are not sure whether we should decide xS or xS. The mathematical rules for handling this type of uncertainty are given by the theory of evidence or the theory of fuzzy measures [Kliv and Folger, 1988].

4. INTEGRATED PROCESSING OF GIS AND RS

4.1 Introduction

Remote sensing is a data acquisition technique. With remote sensing the relative amount of reflected electromagnetic energy of the earth' surface can be determined. Typically, these measurements are stored for every picture element (pixel) in Digital Numbers (DN). The images, resulting from remote sensing, can be characterized by the image space and the feature space.
The position for a pixel is determined by a row- and column-index (i,j) in the image space (Fig. 6). There are no explicit spatial relationships between the pixels in raster.
The (relative) spectral reflectance can be represented in the feature space (Fig. 7). Pixels with similar spectral behaviour can be found in the same region of a feature space.

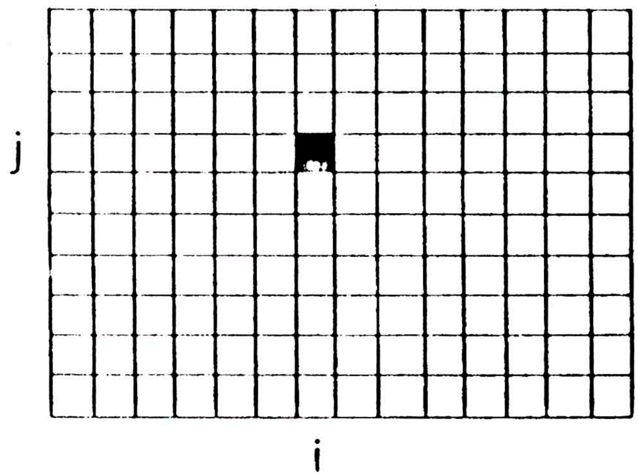

Fig. 6 - Representation of the image space.

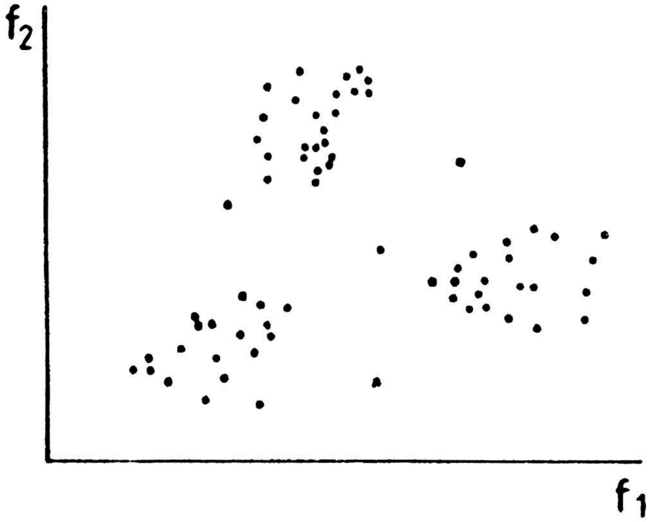

Fig. 7 - Representation of the feature space.

Remote sensing images are widely applied for land cover classification. The results, however, do not always meet the user's expectations. Expectations that are partly based on the possibilities and results of (visual) photo-interpretation. In the visual interpretation a large number of interpretation elements are used: shape, tint, pattern, site, resolution, size, shadow, texture and association [Lillesand and Kiefer, 1987]. In most image interpretation algorithms the only interpretation element being used is spectral reflectance (tint).
The shortcomings of remote sensing imagery for land cover classification can be explained from the characteristics of the imagery. In the image space, no spatial relationships are defined. Therefore, most processing algorithms are per pixel and feature based. Furthermore, because of a limited spectral resolution only a limited number of spectral classes can be distinguished. In order to perform a classification, the user defines his land cover and/or land use classes of interest. Depending on the defined classes, a limited geometric resolution results in so called mixed pixels that cannot be related to a single defined spectral class.
In practice, most users are interested in land use classes: functional classes. Sometimes the relationship between spectral classes and land use classes is straight forward. In a lot of other cases it is simply not possible to derive land use classes from remotely sensed images without the use of ancillary data.
Concerning RS-derived geometric information the same problems show up. There is a limited geometric resolution and a limited number of grey values. Spatial relationships are not explicit and have to be derived from the image itself. Purely image-based segmentations by means of clustering or edge-detection seldom produce results that can meet a user's demand.

Due to the mentioned limitations of remote sensing a certain level of (un-) certainty is related to information that is extracted from the images. The available object information available in a GIS, together with knowledge on the relationships of these objects and spectral data can be used to overcome some of the limitations. An integrated approach, therefore, results in more certainty for the RS derived information. Some examples are described in the following sections.

4.2 Object-classification

In a conventional supervised classification procedure the classes of interest are defined by the user. In an object-classification also the objects of interest are defined by their geometry in a GIS. For every object the land cover class can be derived from the remote sensing image by means of the object-classification [Janssen, Jaarsma and E.T.M. van der Linden, 1990], [Janssen and J.D. van Amsterdam, 1991].
In the applications of the Wageningen Agricultural University, typically, the objects of interest are agricultural fields. In a field (object) one type of land cover is expected. The geometry of the object and the assumption that only one land cover type is expected are exploited in the object-classification. Because the object geometry defines the spatial relationship between a number of pixels the results from an object-classification are more reliable than the results from a per pixel classification. Furthermore, the object geometry enables identification of the boundary pixels. Boundary pixels are often mixed pixels and difficult to classify. By using a technique as polygon shrinking

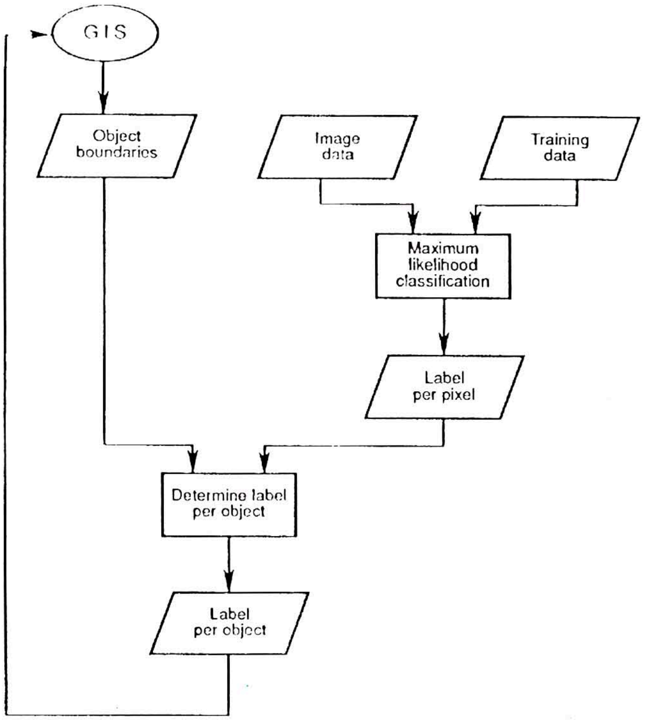

Fig. 8 - Flow chart of the pre-object classification.

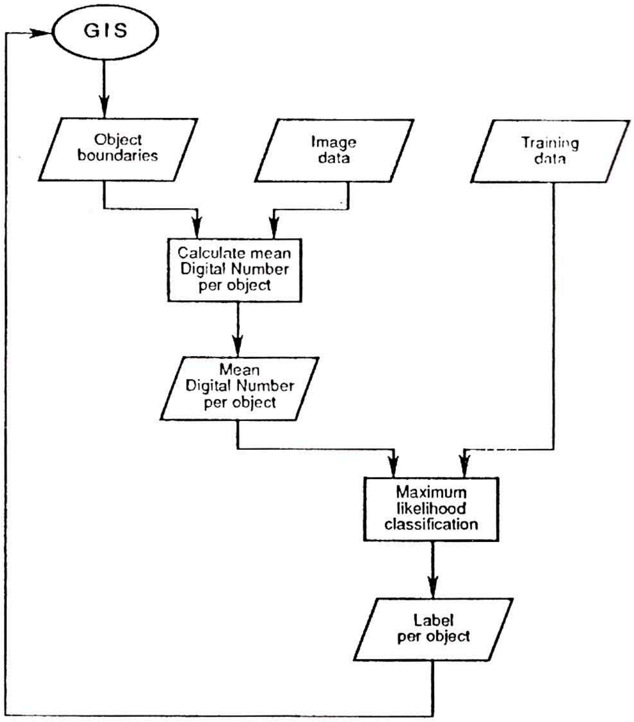

Fig. 9 - Flow chart of the post-object classification.

the boundary pixels can be excluded in the classification of the object.

In most situations, the geometric structure of the remote sensing data are raster based while the object geometry is vector based. The raster and vector data can be combined by a position or object oriented approach [Molenaar and Fritsch, 1990]. In the position oriented approach the object geometry is converted into a raster file and the object-classification is based on an overlay operation of two raster files. In an object oriented approach both raster and vector structure are maintained. In the processing the raster elements that are positioned within an object are identified.

The object classification can be performed at two moments in the classification procedure: pre-object classification and post-object classification:
(i) In the pre-object classification an average reflectance value (in digital numbers) is calculated per object. This mean reflectance value is classified in a maximum likelihood classification. The found label is assigned to the object (Fig. 8).
(ii) In the post-object classification first a per pixel maximum likelihood classification is performed. Subsequently, a frequency table of the labels of the pixels within the object is established; the label with the largest frequency is assigned to the object (Fig. 9).
Both pre- and post-object classification were tested for a number of different areas in The Netherlands. Some results of the post-object classification are described in the following.

A per pixel and object classification were performed with a Landsat Thematic Mapper image (bands 3,4,5) for 7 to 10 different land cover classes depending on the area being classified. The results of a per pixel classification were validated by means of a confusion matrix with reference data resulting in an overall accuracy. The results of the object classification were validated by means of comparison of true- and RS-derived label in the GIS. From this comparison also an overall accuracy was determined.

The per pixel classification yielded overall accuracies of 55% to 76%, the object-classification yielded overall accuracies of 73% to 96%. In general, the classification accuracy improved with approximately 20%. The classification improvement can largely be explained by the definition of spatial context and the exclusion of boundary pixels provided by the object geometry. Besides the improvement in classification acccuracy, the object classification resulted in a label per object and not per pixel.

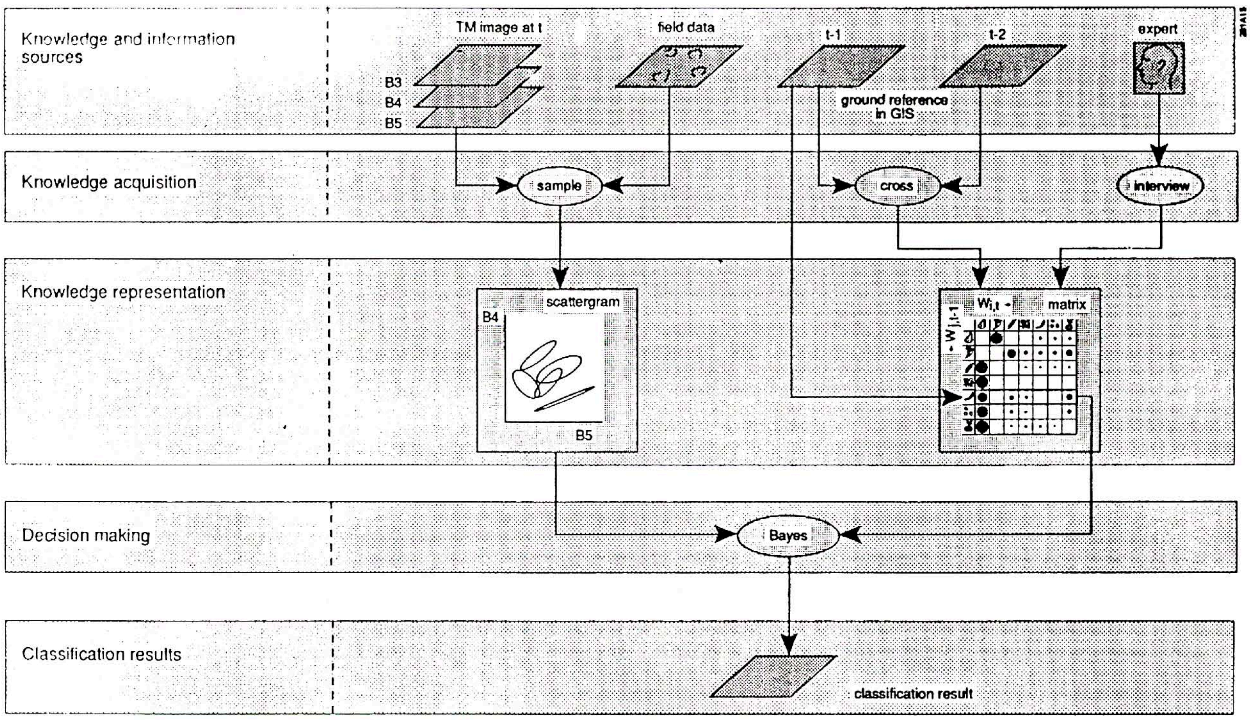

Fig. 10 - Flow chart of image classification with use of information on preceding land cover and crop relation schemes.

4.3 Use of knowledge on preceding land cover and crop rotations

Thematic object data were used to improve classification accuracy by definition of (object) specific a-priori probabilities. This classification strategy was elaborated by [Janssen and Middelkoop, 1991] for an agricultural area in The Netherlands.

In every agricultural region, a limited number of crop rotation schemes are applied for the cultivation of arable land. The information that can be exploited from the rotations schemes is that given a certain crop type at t-1 (one year before acquisition year of RS image), a limited number of crops can be expected at t for the same location. This information was added to the (spectral) information from a remote sensing image to improve the classification accuracy.

The flow scheme of this classification is given in Figure 10. The crop rotation schemes are formalized by means of a so called transition matrix. This matrix can be derived by multitemporal analysis in a GIS or by interviewing agricultural experts. In the transition matrix very specific a-priori probabilities are stored: $P(crop_{i,t}|crop_{j,t-1})$. These a-priori probabilities were combined with the spectral derived information by means of Bayes Rule. The condition to perform this classification is that the crop type at t-1 available.

Unfortunately, the object (field) boundaries were located at different positions in subsequent years. Therefore this classification was realized by a pixel based operation.

To assess the effect of the added information a Thematic Mapper image (bands 3,4,5) was classified for the relevant crops: grass, cereals, potatoes, sugar beets, beans, peas and onions. The classification results were validated by means of a confusion matrix that was based on a cross tabulation of classified and reference data. The overall accuracies of a classification with and without the a-priori probabilities based on preceding land cover and knowledge on crop rotations were 82% and 76% respectively.

4.4 GIS- and KB-supported image segmentation and classification

In this chapter a strategy is decribed to derive accurate land cover data per field for the polder areas in The Netherlands [Janssen and Verwaal].

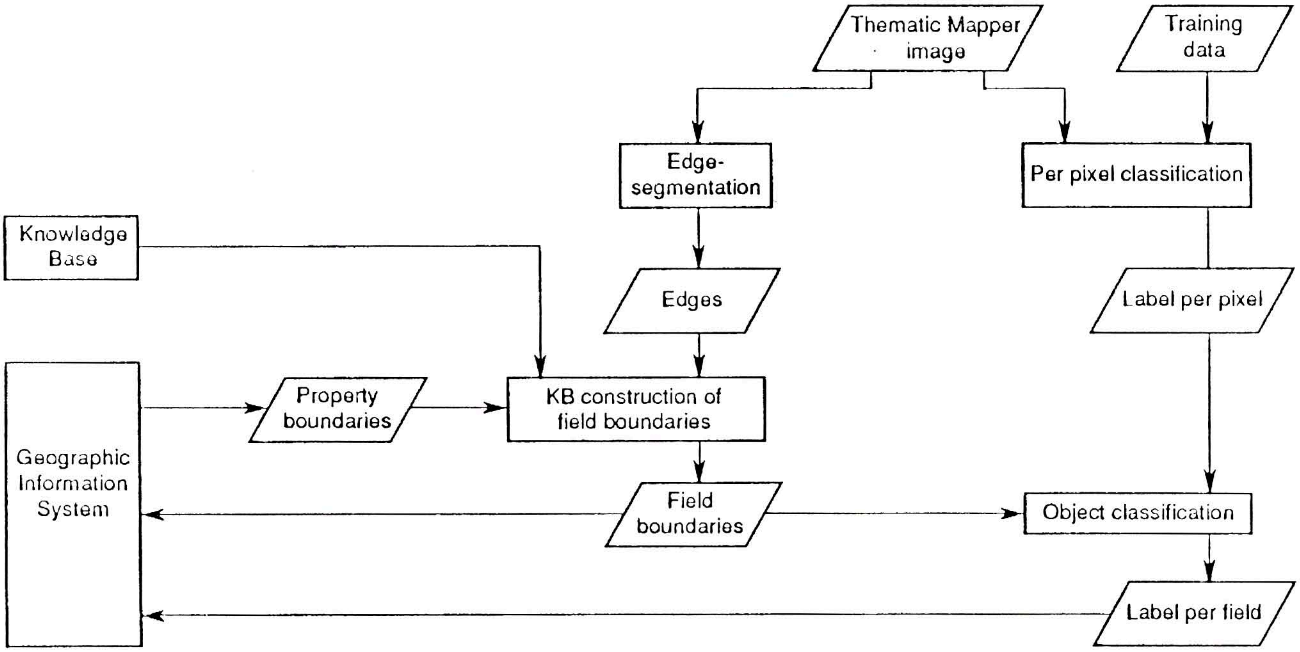

Fig. 11 - Flow chart of GIS and KB based image segmentation and classification.

The polder areas in the Netherlands are characterized by a subdivision in so called 'lots'. One farmer owns one or two lots. In general, the lots have a rectangular shape. Every year a farmer subdivides a lot into several fields (parcels) that are planted (seeded) with a certain crop. A field is defined by having only one type of crop. In the polder areas there are no mixed cultivations. The fields are generally of rectangular shape.
In our terms, lots are aggregated objects with a fixed geometry. The elementary objects are fields with one crop type.

The aims of the developed strategy is to determine geometric and thematic aspects of the elementary objects based on Thematic Mapper data.
Since the geometry of the lots is fixed, it is stored in a GIS. The geometry of the elementary objects is derived by means of a segmentation, the land cover type of every object is derived by means of a classification. The three main components of this strategy can be found in Fig. 11.
(i) The first component is an edge detection by a Kirsch filter. Edges with the largest magnitude and with a minimal length are passed (in vector format) to the knowledge-based (KB) construction of field boundaries.
(ii) The KB-construction consists of a number of operations in which the edges are checked with a number of conditions. Knowledge about straightness and perpendicular intersections are used in the construction. The resulting field boundaries consist of straight arcs that (mostly) intersect perpendicular with the lot boundaries.
(iii) The derived fields are classified by means of an (post-) object classification. The results of the object classification can also be used to find large oversegmentation errors. Oversegmentation means that too much (elementary) objects were detected within the aggrated objects. The single objects with the same thematic label then can be merged. Undersegmentation should be solved by complementary segmentation techniques as region growing. Preliminary results of this strategy seem very promising.

FINAL OBSERVATIONS

Object definitions are always made in a users context, this implies that background knowledge should be available when extracting object information from RS-data. This can be realised partly by the integration of the object data stored in GIS with RS-data. If the integration is only done at a graphical level, i.e. through a graphical overlay then it is the operator at the image processing system who sees the relationships between the GIS-data and the RS-data. He will use the information to steer the image analysis process in an interactive way.
In this paper we proposed an alternative approach where object information stored in a GIS is used to restructure the RS-data so that the pixels are directly related to objects. In this way information about object geometry, object history and object structure can be used to support the image analysis process. Experiments showed that this

information helps to improve the quality of the information extraction from RS-data.

A prerequisite for this strategy is that object information is given explicitely by a GIS, i.e. the data model should support the explicite representation of terrain objects. The link of object data with the raster structured RS images requires in fact a system which can handle object representations in both a vector and a raster format. The link between the two representations will be made through common object identifiers.

We saw that the link of object information to RS-data reduced the uncertainty in RS information extraction. The link does not inprove the accuracy of the original data, neither does it make class definitions less fuzzy. It only gives additional information where the RS-data give insufficient evidence for drawing conclusions about object class or structure, i.e. this link improves the evidence for information extraction.

The methodology described here provides a good tool for monitoring object dynamics. GIS provides a state description of terrain objects, RS can be used to check whether this state has changed and how it has changed. Object knowledge stored in GIS can be used to formulate hypotheses about the changes which might occur. RS can then be used to verify these hypotheses.

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