

Automatically GIS Updating from Classified Satellite Images Using GIS Knowledge

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Abstract: Multispectral classification has a very simple segmentation procedure, since each pixel is viewed as a segment. The neighbourhood pixels are not involved, which is disadvantageous for the accuracy of classification. A method is developed using label and boundary information of a vector format GIS to improve the classification accuracy and to update the GIS automatically. No operational GIS was used. An elementary GIS is created by digitizing a topographic map. After performance of a supervised multispectral classification, the vector format GIS is virtually projected into the image. On the ground of the labels of the pixels (new situation) and of the labels of the GIS polygons (old situation), changes in both labels and boundaries can be detected. Some suggestions for improvement are given.

Introduction

An image can be viewed as a 2-D function of light intensities. After geometric and radiometric restoration and, eventually, enhancement, image analysis can be started. Image analysis consists of two stages: segmentation (or feature extraction) and pattern recognition. The pattern recognition technique mainly applied in digital remote sensing, that is: multispectral classification, has a very simple segmentation procedure, since each pixel is viewed as a segment, i.e. a region which is homogeneous with respect to some property. Each pixel is evaluated separately; the neighbourhood pixels are not involved. The most obvious disadvantage is that the method relies entirely on the multispectral information of each pixel on its own. Actually segmentation can be omitted, since image formation involves already segmentation. The spatial relationships with the neighbouring pixels are not taken into account. This gives cause for several severe problems:

- multispectral classification is very sensitive to noise;
- different objects with the same spectral characteristics can't be distinguished;
- training areas are necessary but because of changing illumination conditions they are only locally valid, i.e. different images need different training samples;
- Texture, e.g. the spatial variance of spectral properties, is left out of consideration and can cause problems.

Interfacing remote sensing images with Geographic Information Systems enables a partial incorporation of the spatial component. However, at present, Remote Sensing Systems (RSS) and Geographic Information Systems (GIS) are poorly integrated. Marble and Peuquet (1983) have summarized a couple of reasons why remote sensing data, especially digital satellite data -although inexpensive- find little application as direct GIS input. The main reason is the lack of accuracy of RS data in both classification and position.

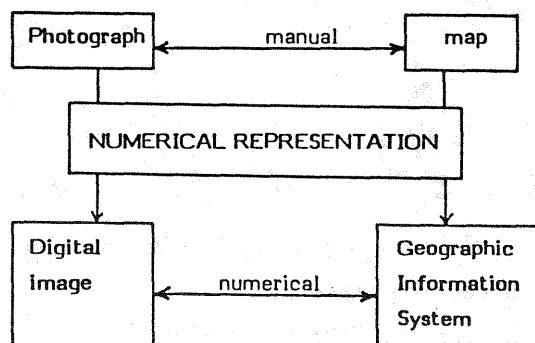


Fig. 1 Basic view on GIS-Digital Image Interaction

Ancillary data, however, can improve substantially both classification and positional accuracy. An important source of ancillary data is a GIS itself. The out of date GIS information can be used to improve the accuracy. Because both GIS and RS raster data are in digital format the

interface can be exerted in a numerical way and the GIS can be updated in an automatic way using the RS data. This approach corresponds literally to the analogue approach in which an interpreter uses map and photograph to extract and store spatial information. The analogy is visualized in fig. 1.

Based on the above consideration in (Lemmens, 1987; 1988) a theoretical outline for the interconnection of RSS with GIS is developed. Starting from a vector format GIS and remotely sensed raster data a computerized interface between both is proposed, using advanced image processing techniques. In the present paper some experiments are described concerning one aspect of the basic concept: automatized updating of a GIS from classified digital satellite imagery, using GIS knowledge to improve the multispectral classification. The results are preliminary. The investigation has the aim to support the theoretical outline. No use was made of an operational GIS. Nevertheless, the background is a practical one. This background will be briefly exposed in the next section. Next, after a brief note on digital satellite images and GIS data-structures, the algorithm to update the vector format GIS from the raster image will be developed. Finally, some suggestions for improvement are given.

Practical Background

Although the method is not implemented in or developed for any operational GIS, the practical background of the present investigation came from local authority needs. For environmental monitoring, local governments need recent information on land use and crop cover. The topographic map, scale 1:25.000, is a useful data source. The revision frequency, however, is once in 5 to 10 years. In many parts of the country the spatial characteristics change much more frequently. Supplementary data is necessary. Aerial photographs, f.i., are appropriate, but costly. Digital satellite imagery, in particular Landsat TM and Spot, seems to be a reasonable, relatively inexpensive alternative.

The spatial information needs for the local authorities cover subjects like:

- town development;
- road planning;
- land use changes, in particular: grass-land, maize fields, bulb fields, green house horticulture, forests and wetlands;
- crop cover;
- manuring amount.

The question is whether the above information is present in TM and SPOT data for the western part of Holland and if so, whether it can economically be extracted. A test area with a large variety in land use and a complex parcel structure was chosen; e.g. a 'difficult' area. Two procedures for information extraction are used:

- manual interpretation of three band colour composites;
- computer assisted multispectral classification.

After extraction the information is stored on maps. No GIS exists at present.

Spatial information gathering often means consulting a lot of different data sources, a very time-consuming procedure. Therefore we investigated the viability of the concepts of computerized RSS-GIS interfacing for this particular case. In doing so, we have neglected the fundamental problems one is faced with in the design of efficient GIS data structures, in the encoding of primary input data (e.g. compilation from maps by manual or electronical digitization), data management and the storage of large volumes of data.

Remote Sensing and GIS integration

In this section first the remote sensing test data will be considered, next, together with a brief consideration on GIS, the GIS data will be the objective and the final part of this section will treat the GIS-TM interface.

The Remote Sensing Data

The digital remote sensing imaging systems collecting frequently spatial data at a fine resolution are the orbital earth resource systems Landsat and SPOT. Landsat produces images of $185 \times 185 \text{ km}^2$ at a pixelsize of $80 \times 80 \text{ m}^2$ (MSS) and $30 \times 30 \text{ m}^2$ (Thematic Mapper) with a temporal resolution of 16 days. The multispectral resolution of the MSS is 4 and of the TM is 6 bands. (The TM is also provided with a thermal band with a pixelsize of $120 \times 120 \text{ m}^2$.) SPOT images cover an area of $60 \times 60 \text{ km}^2$ and have a spatial resolution of $20 \times 20 \text{ m}^2$ in the multispectral mode (3 bands) and even a spatial resolution of $10 \times 10 \text{ m}^2$ in the panchromatic, topographic mode. The orbit repetition is 26 days, but the observation repetition is much higher. SPOT has topographic accuracies up to a scale of 1:50.000.

SPOT data have a better spatial resolution than Landsat TM data, so SPOT images would be more appropriate with regard to the complex spatial structure of the area, but at the time of the start of the investigation no SPOT images of the test area were available. A second reason

to use Landsat TM is its spectral resolution, which is twice as high the SPOT spectral resolution.

Two Landsat TM frames were involved. One of 4 - 11 - 1985 (winter image) and one of 3 - -8 1986 (summer image). Both are used for manual interpretation and multispectral classification. Some radiometric and geometric restorations are carried out. Because of the mirror effect of the greenhouses a radiometric restoration of the summer image was necessary. To transform the image into the topographic map reference system a geometric restoration was carried out, assuming an affine transformation model. The transformation parameters are determined by 15 control points. The resampling, necessary after each geometric transformation of digital images, was done by cubic convolution. For a better connection with the grid of the topographic map (1 km x 1 km), the pixels are further resampled to size 25 x 25 m².

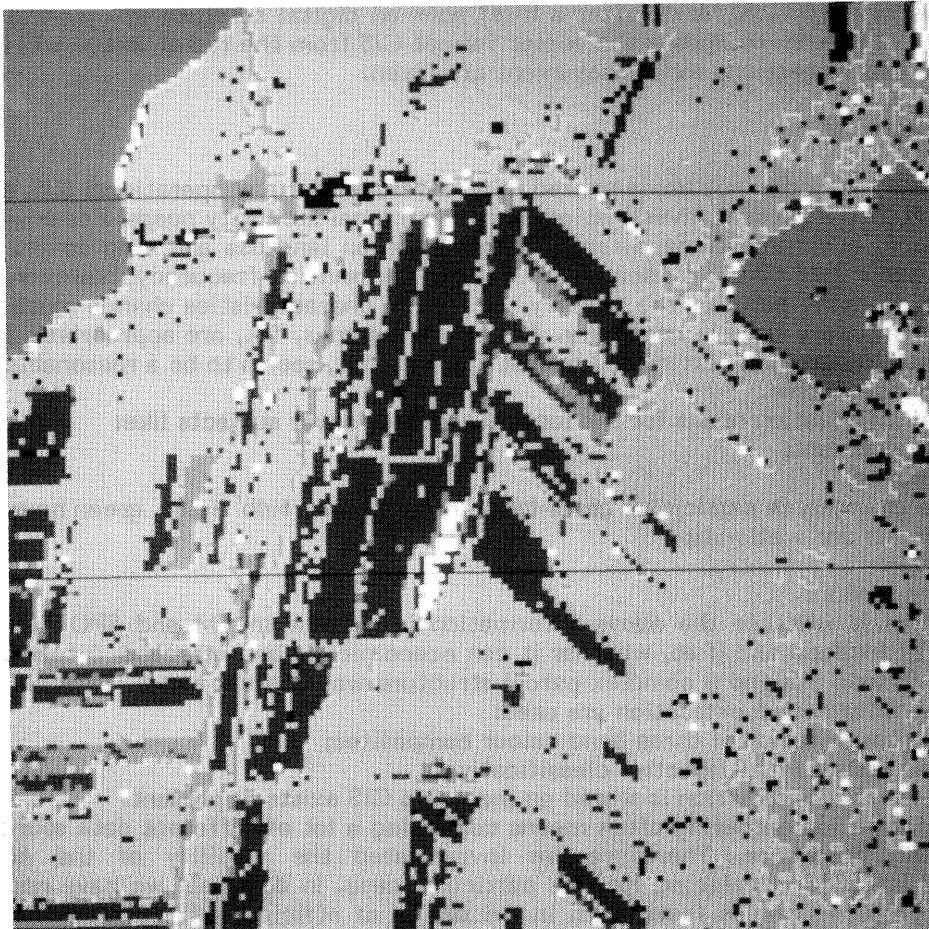


Fig. 2 The result of multispectral classification

A multispectral maximum likelihood classification is carried out, using band 1, 4, 5 and 7. Analysis shows that the other bands add only little information. The winter area shows the best results. 11 Classes are distinguished, including 'unknown', which is much more differentiated than the thematic information on the topographic map. Because the GIS is compiled from the map, a reduction of the 11 classes to 6 classes is established. The thematic transformation is shown in table 1. Fig. 2 shows the classified area (6 classes).

GIS

A GIS efficiently stores, retrieves, manipulates, analyzes and displays spatial data (Marble and Peuquet, 1983). Its purpose is to store large volumes of cartographic and thematic data in a convenient and fast accessible way. GIS data consists of: (1) positional data and (2) thematic (semantic) data. The labels of the positional data are co-ordinates, very often longitude and latitude referenced to an ellipsoid. Good photogrammetric sense dictates that the co-ordinates should be provided by an accuracy measure. The labels of the semantic data are attributes. They can either be qualitative (f.i. land use) or quantitative (Jensen, 1986). Because the phenomena on the surface of the earth change rapidly, especially by human interference, time, as a third component, is important. This time aspect causes that the GIS has to be updated.

The fundamental spatial data types are: (1) points, (2) lines and (3) areas. Often a set of

connected lines, e.g. polygons, are added as fourth type. For digital storage and handling the geographic data have to be encoded and structured. Encoding can be done in several formats (Jensen, 1986):

- Each point is stored in Cartesian (X, Y, Z) or geographical (ϕ, λ) co-ordinates;
- Nodes, line segments and polygons are stored in a topological way;
- The data is stored in raster format.

Co-ordinate encoding leads to polygonal or vector format GIS. An example of a partly topological GIS is DIME (Dual Independent Graph Encoding) developed by the US Bureau of Census. Both Cartesian co-ordinates and topological codes are stored. The map is stored as a graph. To each node the Cartesian co-ordinates are added. Raster encoding means actually that a grid is superimposed over the surface of the earth. Each grid element is provided with attributes. Each attribute may be viewed as an overlay. The grid size depends on the application and the available information density. It can vary within one GIS. Raster storage takes a large computer volume, but the interface with digital image data is fast and easy. A raster GIS extensively described in literature is IBIS (Marble and Peuquet, 1983).

TM label	map label
grass-land wet dry other	grass-land
urban area and roads	urban area and roads
surface water	surface water
fallow land winter crop bulb fields	fields
foliage trees	forest and orchard
wetlands, dunes and grass verges	-
unknown	unknown

Table 1

Data structure is, besides the tremendous amount of data, one of the most severe problems in GIS design and usage. In the course of time several data structures have been developed, like hierarchical, relational, network and semantic, but none of these have proved to be fully satisfying. At the moment the GIS community keeps an eye on Artificial Intelligence. One has to keep in mind, that AI is based on a combination of older search techniques, efficient storage and symbolic data comparison. The computer languages are optimized for handling symbolic data, but an operational design needs very fast hardware.

Coordinate File				Label File			Look-up Table	
polygon number	vertex	X	Y	polygon number	label	area (m ²)		
23	1	715	490	23	3	35763	1:	surface water
	2	785	595				2:	grass land
	3	880	485				3:	forest and foliage trees
	4	935	660				4:	fields
	5	745	710				5:	urban area and roads
	6	660	645				6:	unknown

(a)

Table 2

(b)

(c)

To carry out the experiments a 4 x 4 km² sized area of the topographic map, scale 1 : 25.000 is manually digitized. Fig. 3 shows a plot of the digital map. Regarding the area size the complex parcel structure is obvious. Like the multispectral classification is behind our interest, we didn't pay much attention to the GIS design. We use a very simple data structure. Each parcel is

represented by a polygon to which a unique number and a label, compiled from the map, is attached. The label is represented by a number. The meaning can be found in a look-up table (see table 2c). Together with the area size, computed with the expression:

$$O = \frac{1}{2} \sum_{i=1}^n X_{i+1} (Y_i - Y_{i+2})$$

these features are stored in the label file (see table 2b). The co-ordinates of the vertices of the polygon are stored in the co-ordinate file (see table 2a) The access is also the parcel number.

The Interface

Before the image and the GIS can be interfaced they must be referenced to the same co-ordinate system. For scanner data mostly a polynomial geometric transformation model is assumed. The actual parameters of the polynom are determined from control points. With more control points than unknown parameters a least squares estimation can be established. Between topographic map and TM image an affine transformation is assumed, that is:

$$\begin{aligned} x &= a_0 + a_1x + a_2y \\ y &= b_0 + b_1x + b_2y \end{aligned}$$

with:

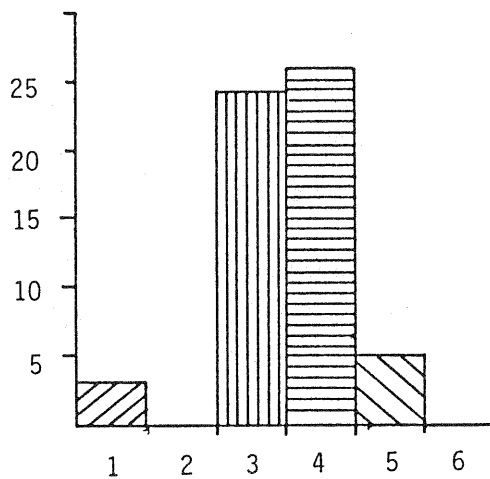
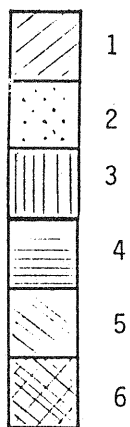
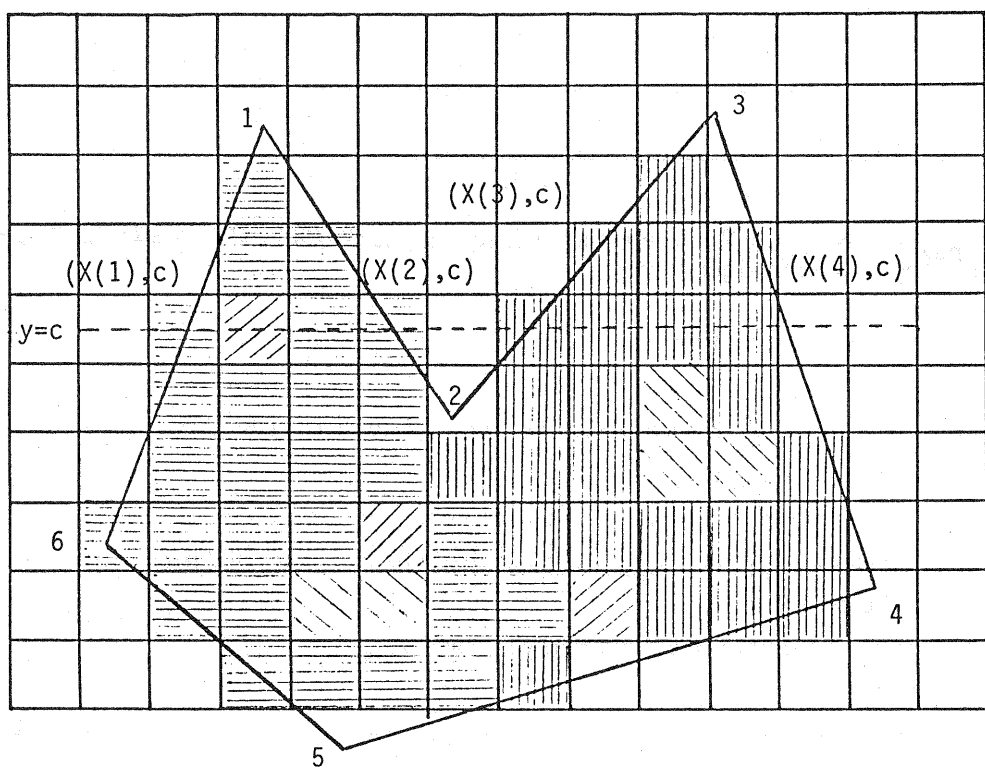
- (x, y): image co-ordinates
- (X, Y): map co-ordinates
- (a_i, b_i): i=0,..,2 transformation parameters



Fig. 3 Plot of the GIS, dimension: 4 x 4 km²

Between the map and the digitizer a similarity transformation is assumed. Once the transformation parameters are known, the nodes of each GIS parcel are backprojected into the classified image, in order to detect changes in landuse and boundaries. This investigation concentrates on detection of landuse change. From the backprojection all the pixels inside the parcel can be determined.

The method is as follows (see fig. 4a). Each x-line, falling between the y-range of the parcel is intersected with the polygon sides. Given the co-ordinates of the vertices, the parameters (a,b) of the line equation $y = ax + b$ can be determined. The equation of the raster line in x-direction is given by $y = c$, with c an integer and $y_{min} < c < y_{max}$. The intersection point is given by $((c - b)/a, c)$ and the intersection pixel by $(\text{nint}((c - b)/a), c)$, with $\text{nint}(x) = [x]$, the nearest integer of x. These pixel co-ordinates are stored in the vectors X(i) and Y(i), $i=1,..,n$, with n the number of intersection points. When all intersection pixels of an x-line with the polygon sides are determined, X(i) and Y(i) are ordered in ascending values of X(i). Note that for each x-line Y(i) is constant. The pixels between an odd and an even intersection point are part of the polygon. Since the polygon is a closed area, the number of intersection is even. The pixels P(i,j) on the x-line belonging to the polygon and their number n can now be determined.



(a)

(b)

Fig. 4 Projection of a GIS parcel into the image

For each label the number of pixels to which this label is assigned, is stored in a frequency histogram $N_{\text{label}}(P(i,j))$ (see fig. 4b). After the polygon is evaluated the label frequency histogram contains the information about the present state. This state may be corrupted by noise and misclassifications due to the reasons mentioned in the introduction. The label L_{max} having the largest number of pixels $N_{L_{\text{max}}}$ is determined from the label frequency table. The relative frequency RL_{max} is computed according to:

$$RL_{\text{max}} = \frac{N_{L_{\text{max}}}}{N_{\text{tot}}} \cdot 100 \%$$

with N_{tot} the total number of pixels of the parcel.

If RL_{max} exceeds a certain threshold T , it is very likely that the polygon has the present label L_{max} . This label may be the same as the GIS label. In that case the situation has remained unchanged. If $RL_{\text{max}} < T$, then a further evaluation must be carried out. This evaluation is not yet implemented. It will be discussed in the last part of this section.

Example: In table 2a it is shown that parcel 23 has GIS label 3. Its label frequency is shown in table 3 and sketched in fig. 4b.

Polygon 23:	label L_i	1	2	3	4	5	6	
	number of pixels	3	0	24	26	5	0	tot. 58

table 3

$N_{\text{tot}} = 58$, $L_{\text{max}} = 4$, $N_{L_{\text{max}}} = 26$. The relative frequency is $(26/58) \cdot 100 \% = 45 \%$. The above is summarized in the following algorithm:

1. For each GIS polygon of interest
 - begin
 2. Transform the co-ordinates of the vertices of the GIS to the image reference system;
 3. Compute a and b ($y = ax + b$) for each polygon side;
 4. Determine y_{min} and y_{max} , the NINT of the minimum and maximum y-value of the polygon;
 5. For each x-line, $y = c$, between y_{min} and y_{max}
 - begin
 6. Compute the co-ordinates of the intersection points $X(i)$, $Y(i)$, with $Y(i) = c$, and order them such that $X(i+1) > X(i)$;
 7. Determine the pixels between $X(k)$ and $X(k+1)$, with $k = 1, 3, \dots$, giving $P(i,j)$ and the number n ;
 8. For $l = 1$ to n

$$N_{\text{tot}} = N_{\text{tot}} + 1, N_{\text{Label}}(P(i,j)) = N_{\text{Label}}(P(i,j)) + 1$$
 - end
 9. Determine L_{max} such that $N_{\text{Label}}(L_{\text{max}})$ is maximum and $RL_{\text{max}} = (N_{\text{Label}}(L_{\text{max}})/N_{\text{tot}}) \cdot 100 \%$;
 - 10 If $RL_{\text{max}} > T$ then
 - 11 If $L_{\text{max}} = \text{GIS Label}$ leave GIS Label unchanged
 - 12 If $L_{\text{max}} \neq \text{GIS Label}$ new GIS Label = L_{max}
 - endif
 - 13 If $RL_{\text{max}} < T$ leave GIS Label unchanged
 - end

Casting a glance at the label frequency histogram learns that label 3 has also a rather high frequency. It is unlikely that this is only caused by misclassifications due to the factors mentioned in the introduction. It is much more likely that a part of the parcel has changed label, i.e. a new boundary is created. A clustering method, e.g. a region growing technique, is able to check whether the pixels with label 3 form a region or are just randomly distributed. Region growing techniques extract homogeneous regions. An initial small region is extended by joining the neighbouring pixels which have the same characteristics. In this case the characteristic is the label; adjacent pixels with the same label are joined to a region. If the number of adjacent pixels exceeds a certain threshold, it is likely that a new parcel is created. The threshold may be a function of both the classification accuracy and the locational accuracy.

When the pixels form a region, the border can be extracted using binary line-following techniques, and represented by a chain code (see, f.i., Rosenfeld and Kak, 1982, vol. 2, pag. 197-199). By intersection the raster line can be transformed to a vector line.

Results and discussion

Our starting point is that the thematic information is, in principle, present in the multispectral data. Of course, this should be investigated in advance. The present investigation was parallel to the test of the suitability of satellite imagery for environmental studies. The results of the last were rather poor. The estimated classification accuracy even didn't reach 70%. This figure is derived from a comparison of the manually interpreted TM color composite and the maximum likelihood classification. As a result the local government even skipped digital satellite data as alternative spatial data source. The poor classification accuracy is due to the large variety in land use and the complex parcel structure. For other parts of Holland, however, satellite data have proven to be appropriate for environmental studies. Classification accuracies up to 90% could be reached.

The present investigation shows that, using a rather simple GIS, an automated update of a GIS by classified digital satellite imagery can be performed and that the classification accuracy increases. Only thematic changes can be detected, no changes in boundaries. Besides segmentation by edge detection and line-following in the original image, both are out of the scope of this investigation, new boundaries can be detected by more advanced usage of label information. We have only considered the number of pixels belonging to each label, represented by a label frequency histogram, to test whether changes appear. But also the spatial distribution can be taken into account. This purpose requires the incorporation of segmentation techniques like region growing and line-following.

With the suggested extension also new boundaries between parcels, i.e. one parcel is divided into several parcels, can be found, but not new line elements like roads and ditches, and also not vanished boundaries. To do so, boundary detection techniques are required. They operate on the original, eventually preprocessed image. Knowledge on the geometric accuracy of both GIS and RS data has to be used in order to obtain an advanced procedure.

Conclusions

According to the concepts developed in (Lemmens, 1987; 1988) it is shown that it is possible to interface multispectrally classified RS raster data with a GIS in order to automate the update of the GIS and to improve the classification accuracy. Of course, the thematic information contents of the data must be sufficient. The accuracy of both the classification and the position has to be incorporated in order to improve the results. The present design can only detect thematic changes, no locational changes. Further research has, in first instance, to be focussed on the detection of boundaries in the original image, using boundary detection techniques. The statistical aspects have to be extended. To check whether a small amount of pixels with an anomalous label form a region, cluster techniques have to be implemented. Entirely automated GIS updating will probably stay wishfull thinking. There will always stay an uncertainty range, in which a human operator has to decide.

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