CHANGE DETECTION IN URBAN AREAS USING SATELLITE IMAGES AND SPECTRAL MIXTURE ANALYSIS

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ABSTRACT:

Monitoring changes of the environment is a problem faced by many different institutions today. Especially government agencies have the duty to detect and record these changes which may take place in urban, forest, agricultural, desert areas, and so forth. The challenge is to gather the necessary information at acceptable costs and to develop suitable techniques to detect and record the changes in question. Due to their low costs of recording data and their spatial, spectral, and temporal resolution, satellite sensors are very suitable for a number of different applications. As the sensors supply large quantities of data the techniques used for the analysis of the recorded satellite images should not only be reliable but also very efficient. The strategy proposed in this paper applies a spectral mixture analysis to satellite images and uses the results of this analysis for change detection in an urban area. It will be shown how those areas, where construction activities have taken place, may be derived and highlighted to facilitate the update of existing landuse data bases.

1. INTRODUCTION

Cities are constantly developing, and to keep up with the changes is a very difficult task for urban and regional planners. The challenge is to gather the necessary data at acceptable costs in the intervals required, and to develop suitable techniques for the extraction of the required information. For urban studies this task is typically done by photo interpretation. Small-scale photographs (e.g. 1:10,000 and larger) and vertical stereopairs from mapping cameras are used for urban studies on a general scale. Air photography has the disadvantage of being very expensive in obtaining the pictures, making regular repeat coverages prohibitively expensive (Richards, 1992). Also a lot of manpower and time is needed for the analysis of analogue photographs. Compared to areal photography, satellites offer a number of advantages which are necessary for a system, that will be used for change detection, despite their still rather coarse resolution (e.g. Landsat TM, 30 x 30 m^2). These advantages are: regular repeat coverage; recording data from the same geographic area at the same time of day; maintaining the same scale and look-angle; recording reflected radiant flux in consistent and useful spectral region; and lower costs compared to ohter mehtods (Jensen, 1986). As the spatial resolution of satellite systems improves, it will be easier to take advantage of these features, but even today satellite images may be used for change detection in urban areas. A number of techniques are being used for these purposes. These include image differencing, image overlay, image ratioing, classification comparison, principal component analysis, and change vector analysis (Jensen, 1986). These methods have the disadvantage of either supplying no information as to the nature of the change or being very cumbersome to implement. The aim of this study is to show how satellite images, recorded at different dates, which were transformed using the spectral mixture analysis (SMA), can be used to determine where building activities have takem place.

The SMA has been used in a number of studies in the natural environment, for instance in the estimation of sediment concentration in the Amazon River (Mertes et al., 1993), the analysis of rock and soil types at the Viking Lander 1 Site (Adams et al., 1986), the abundance of vegetation in deserts (Smith et al., 1990), and the analysis of inland tropical water (Novo and Shimabukuro, 1994). The SMA has also been used for classification and consequent change detection (Adams et al., 1995) and for mapping evaporite minerals on a playa surface (Bryant, 1996). One study using the SMA in an urban environment deals with the analysis of data collected by an airborne thematic mapper (ATM) of the University College of Swansea, UK (Foody and Cox, 1994).

Two Landsat TM quarter scenes covering the City of Vienna were available for this study. The images were recorded on June 5, 1986 and July 1, 1991. Of the seven available bands the six reflective bands covering the visible light and parts of the near and middle infrared were used. Except for geocoding the images were not pre-processed in any other way.

2. IMAGE ANALYSIS

2.1. Spectral Mixture Analysis

The aim of SMA is to estimate how each ground pixel's area is divided up among different cover types. The results are a series of images, each the size of the original image, and each giving a map of the concentration of a different cover type across the scene (Settle and Drake, 1993). Before these proportions can be calculated a set of spectra is defined called "image endmembers", representing the spectral reflectance of the different cover types. Different approaches have been used to define these endmembers. These include pixel vectors, training areas, laboratory data, or a combination or these methods. When mixed using the appropriate rule, these endmembers reproduce all of the pixel spectra. The maximum number of endmembers is limited by the number of spectral bands of the satellite image. Due to the fact that some bands are highly correlated, the number of endmembers necessary to explain an image adequately is in general smaller than the number of bands. To identify the intrinsic dimensionality of the data, the principal component analysis may be used. The number of components showing meaningful information equals the smallest number of endmembers needed to construct a linear mixture model (Settle and Drake, 1993). The endmembers are selected from areas which show only or almost only the surface material in question, and which receive maximum illumination. In addition an endmember called "shade" is introduced, which accounts for variations in lighting at all scales (e.g. changes in incidence angles, shadows cast by topographic features, subpixel shadows cast by trees, and so forth). Once the endmembers are defined the fractions of each endmember in each pixel may be calculated by applying the appropriate mixing rule. A general equation for mixing is (Adams et al., 1989):

$$DN_c = \sum_{n=1}^{N} F_n \cdot DN_{n,c} + E_c \qquad (1)$$

where

$$\sum_{n=1}^{N} F_n = 1 \qquad (2)$$

with

DN_c	radiance in channel c,
N	number of endmembers ,
F_c	fraction of endmember n,
$DN_{n,c}$	radiance of endmember n in channel c,
E_c	error for channel c of the fit of N spectral endmembers.

Equation (1) converts the DN value of each pixel in each channel to the equivalent fraction (F_c) of each endmember as defined by the endmembers ($DN_{n,c}$). The error (E_c) accounts for that part of the DN-value which is not described by the mixing rule. Equation (2) introduces the constraint that all fractions of a pixel must sum to one.

Three ways exist to evaluate the results of the spectral mixture analysis. These are the visual analysis, the calculation of the root-mean-squared (rms) error, and the calculation of the fraction overflow (Adams et al., 1989).

With the visual analysis of the fraction images, the analyst determines whether they results consistent with other information existing about the area in question. If the patterns do not correspond with the additional information obtained by ground truthing or other sources then the model constructed may not be correct.

The second test is the calculation of the rms error. It is based on the E_c term of equation 1, squared and summed over all M image channels (see (3)) (Adams et al., 1989) .

$$\varepsilon = \left[c^{-1} \sum_{c=1}^{k} E_c^{\,2} \right]^{1/2} \qquad (3)$$

with

ε root-mean-squared (rms) error

k number of Channels

The rms error is calculated for every pixel individually and can also be visualized as an image. It may also be calculated for the whole image, showing the overall rms error. A small rms error is an indication of a mathematically good model. A high rms error indicates that the model has not been constructed correctly.

The third test is the computation of the fraction overflow. Reason dictates that the fractions of the land cover components should lie between zero and one, but if the model is not constructed correctly fractions may fall outside this range. As the endmembers are supposed to represent 100 % of the land cover in question, any pixel having a higher portion of the land cover as compared to the endmember, will have a fraction higher than one. To satisfy the constraint that all the fractions of a pixel must sum to one, the fraction of another endmember of this pixel will be below zero.

If the model is not satisfactory according to the tests described above, the endmembers must either be changed, deleted, or additional endmembers must be defined. The following rules aid in the selection of new endmembers. An overflow in a fraction image is an indication for a pixel, which represents the land cover better then the pixel used for the definition of this endmember up to now. An overflow and a high rms error in a pixel may be due to an unmodelled endmember which is represented by that pixel (Adams et al., 1989).

2.2. Results

The endmembers selected for the analysis represent vegetation, water, built-up areas, and shadow. The limitation to this number of endmembers was confirmed by the principal component analysis. To define the endmembers, pixel vectors were examined which only or nearly only represent the land cover in question. The pixel vector chosen for vegetation has a very high value in the near infrared band 4, as this band is best for picking up vegetation. The endmember for water is defined by a pixel vector located in a faster flowing part of the Danube in the North of Vienna, and the endmember for built-up areas is defined by a pixel vector located in an administration building. As shadow represents areas not or badly illuminated, this endmember was defined as zero in all six bands although it is possible that the shade endmember is greater than zero, owing to instrumentation offsets and/or gain, skylight scattering, and so forth (Adams and Smith, 1986). Endmembers were selected for both images, using the guidelines described above. Table 1 shows the values of these endmembers for both images. As can be expected the values of an endmember in 1986 is very similar to 1991. Differences are due to the fact that the images were not spectrally calibrated and to seasonal changes. The endmembers have a high spectral contrast which is necessary for a successful separation.

Endmember TM Channel	Vegetation (86/91)	Built-up Area (86/91)	Water (86/91)
1	85/70	147/151	99/96
2	35/32	72/79	43/45
3	27/24	86/99	40/49
4	152/161	77/92	26/27
5	88/106	133/165	9/7
7	25/31	86/97	6/5

Table 1:DN-Values of Endmembers for 1986 and 1991

Using the selected endmembers the mixture rule (1) was applied to both satellite images individually, resulting in three fraction image per image, giving the proportions of vegetation, built-up areas, and water plus the shadow and the rms-error images. The fractions are rescaled according to the rules of table 2 to allow visualization.

Fraction	**Fraction Image Value**
< -1	0
-1 to 0	0 to 100
0 to 1	100 to 200
1 to 1.55	200 to 255
> 1.55	255

Table 2: Rescaling of Fraction Images

The next step is to use to use the fraction images to determine those areas, where building activities have taken place.

3. CHANGE DETECTION

The method used here to detect urban growth is closely related to image differencing. The main use of this technique so far has been in subtracting bands or principal components from one another. Both have the disadvantage that neither individual bands nor principal components contain information which may be regularly related to a special land cover type. Fraction images, on the other hand, offer the advantage of containing a priori defined qualitative information (certain land-cover type). The method to detect changes suggested here is to subtract fraction images from one another, which represent the same land cover type, calculated from satellite images recorded at different dates. If the fraction images represent the same type of information changes should be clearly seen, as the fraction images values must be higher or lower for pixels, where the land cover type has changed compared to a pixel from an earlier date. Two premises must be satisfied before a change detection may be attempted. First it is necessary to make sure that the fraction images actually represent the same information. To check this, the histograms of both fraction images are compared. If the information is the same, then the general shape of the curve must be approximately the same as well, except for minor differences which are due to land cover and seasonal changes. Also, one must make sure that the information shown by the fraction images is as pure as possible, i.e. only the land cover type in question is represented. If that is not the case, the change detection will be negatively influenced, and methods must be found to remove these influences. To do that the inclusion of one or more other fraction images in the change detection might be advisable. Figure 1 shows a comparison of the histograms of the fraction images for built-up areas for 1986 and 1991.

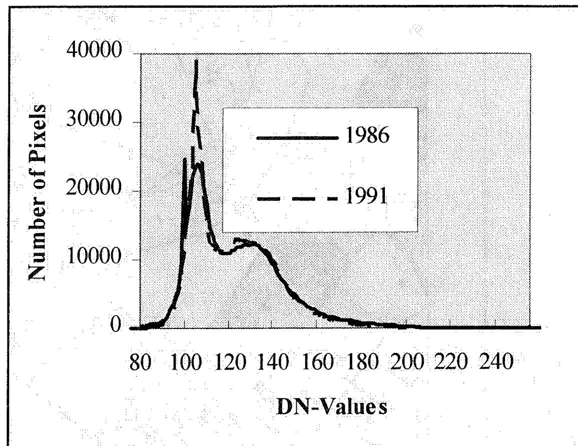

Figure 1: Histogram of the Fraction Images for Built-Up Areas for 1986 and 1991

As the histograms of 1991 has a shift of 5 DN-values to the left, as compared to the histogram of 1986, the 1991 histogram was corrected by these 5 DN-values for the comparison. The histograms have a very similar shape, with the exceptions of a peak at DN-value 100 in the 1986 histogram and a peak at DN-value 105 in the 1991 histogram. These peaks are due to different cloud covers in different parts of the image and changes in vegetation. As these differences are in areas where there are no buildings (a DN-value of 100 is equivalent to a fraction of 0), these slight differences will not affect the change detection.

The next step is the subtraction of the fraction image for 1986 from the fraction image for 1991. The result is a new image, and to show the areas of interest, all pixels which have a positive difference of more than 20 are highlighted. The threshold value of 20 was found to be most suitable after examining different values. A problem encountered here is the differentiation between bare soil and built up areas. To overcome this problem, the fraction image for water from 1991 is also included to make the differentiation more reliable. It was found that very low values in the fraction image for water and high values in the fraction image for built-up areas is an indication of bare soil rather than buildings. Although the change detection was carried out for the whole city of Vienna, a development area in the north-east of Vienna was chosen to examine the results of the method in detail. The result of this analysis is a map (Figure 2) which shows where building activities have taken place (black), or might have taken place, but are more likely to be fields (grey).

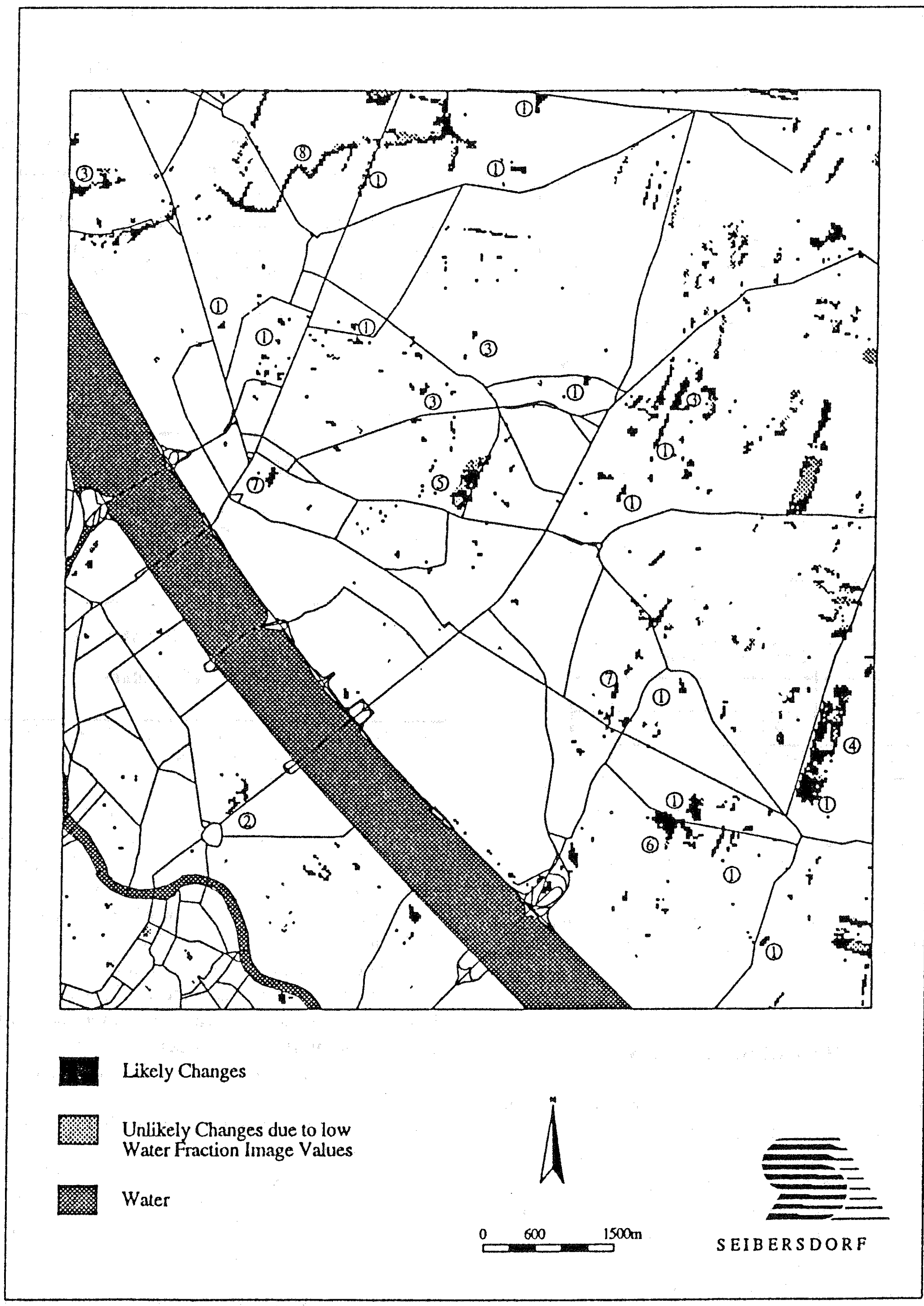

Figure 2: Changes Due to Building Activities from 1986 to 1991 in the North-East of the City of Vienna

# in Figure 2	Construction Activity
1	Residential Areas
2	Office Blocks
3	Industrial Zones
4	Allotments
5	Veterinarian Faculty (under construction)
6	Hospital (SMZ-Ost)
7	Administration
8	Irrigation Canal (under construction)

Table 3: Detected Construction Activities from 1986 to 1991

A ground truthing was conducted and the confirmed changes are marked with numbers in figure 2. Table 3 shows to which changes the numbers in figure 2 correspond. Twenty-three changes were identified. As may be expected, most changes took place in residential areas (1) and industrial zones (3).

4. SUMMARY

The procedure proposed here for change detection uses the spectral mixture analysis to transform satellite images which were recorded at different dates. The results of these transformations, the fraction images, show the proportions of different cover types across the scene. The cover types are a priori spectrally defined by pixel vectors, which show only or nearly only the surface material in question. This was carried out for the for two Landsat TM images of the City of Vienna, recorded in 1986 and 1991. Three endmembers were defined for the cover types vegetation, water, and built-up areas. The fraction images for built-up areas were then compared to determine those areas where building activities have taken place. The results were verified by ground truthing, where most of the changes could be confirmed.

5. DISCUSSION AND CONCLUSION

The procedure presented here for change detection offers a powerful tool for city planners, as it not only gives accurate information as to where changes have taken place but can also be carried out in a very short time. Costs are not only saved in the collection of the data but also in the analysis of the satellite images as compared to other methods. Further analysis for the update of landuse data can be limited to the areas shown by this method. By combining the benefits of the high spectral resolution of the Landsat TM and the high spatial resolution of newer systems (e.g. panchromatic MOMS) the interpretation of the results could be greatly improved. It would be possible to examine those areas, where changes are supposed to have taken place by a visual analysis of the high resolution data. The use of the fraction images is not limited to change detection in urban areas but may also be used in other environments.

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