Urban Environment change detection through landscape indices derived from Landsat TM data

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Abstract:

This paper describes some results of change detection in Tokyo metropolitan area , Japan , using the Landsat TM data, and methods to quantify the ground cover classes. The changes are analyzed using the measures of not only conventional spectral classes but also a set of landscape indices to describe spatial properties of ground cove types using fractal dimension of objects, entropy in the specific windows defining the neighbors of focusing locations.

In order eliminate the seasonal radiometric effects on TM data, an automated class labeling method is also attempted. Urban areas are also delineated automatically by defining the boundaries of the urban area. These procedures for urban change detection were implemented by the unified image computing methods proposed by the author, they can be automated in coherent and systematic ways, and it is anticipated to automate the whole procedures.

The results of this analysis suggest that Tokyo metropolitan area was extended to the suburban areas along the new transportation networks and the high density area of Tokyo were also very much extended during the period between 1985 and 1995.

Key words: change detection, TM image analysis, Automated image analysis, Urban Environment, Landscape indices

I. Introduction

Application of remote sensing to the change detection of urban environment is one of common interests in remote sensing communities in the world, since the first remote sensing satellite was launched in about 30 years ago. It is well known that remote sensing provides integrated and comprehensive data sets for urban environments analysis, but there are still a lot of tasks to be studied in image analysis methods as well as in urban environment itself.

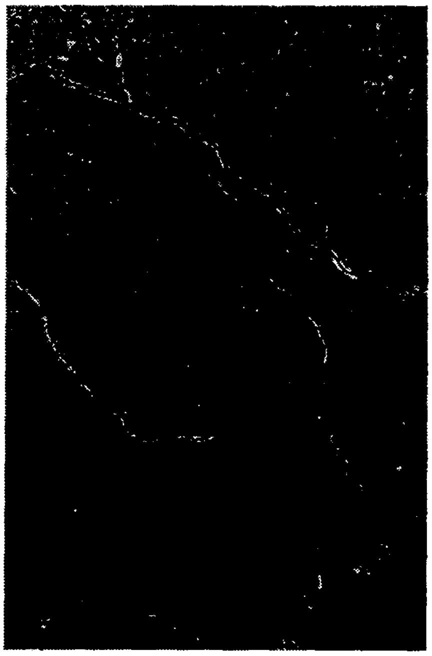

Figure 1 Landsat TM Band 4 sub-image of the Study Area, Kanto District, including greater Tokyo metropolitan and the City Center of Tokyo, January, 1995..
The data of January, 1985 and November 1999 are also used for change detection

Tokyo metropolitan area is selected as the study area. As well known, Tokyo is one of biggest cities in the world,
and it is still growing and being developed. There were enormous development activities due to economic prosperity of Japan during the decades between 1980s and 1990s. In some cases, the impact of the development has become more serious. For an example, recent ground covers changes induced a serious micro climate problems called "heat island "phenomena, which is considered as major causes of heavy shower targeted to specific small areas of Tokyo urban areas.

The urban area of Tokyo has specific characteristics compared with those of other major cites in the world in term of remote sensing: house size and road and high-way widths are much smaller, but there are a lot of tall buildings are mixed as well as low story-houses. Therefore, the spectral responses from urban components will be very different and difficult to treat the small parcels at TM spatial resolution of 30m.

Remote sensing has been and is believed that it is a good information source to detect, analyze and model the urban environment. However, it is not so easy tasks to apply remote sensing operationally to detect those changes, especially radiometric environment such as atmospheric quality and sun illumination angles varies at every moment.

This paper addresses to explore two points: how to obtain spectral thematic maps from remotely sensed data that can fit for temporal analysis and how to quantify the spatial patterns of groundcover classes to assist the interpretation of urban environment.

II. Approach:

With the remote sensing based change detection, it is popular to compare the thematic images(or classification maps) pixel-by pixel basis or to generate class transient vectors. However, this kind of presentation methods for changes does not take in account of spatial pattern changes . Change of spatial pattern of ground cove types or classes will be more significant to understand the environment of urban area as well as that of nature.

With ecology science, a concept of landscape indices has been developed during the past a few decades Landscape indexes is indexes of landscape structure (pattern), including richness, evenness, patchiness, diversity, dominance, contagion, edges, fractal dimension, nearest neighbor probability, and the size and distribution of patches.

In this study, the notion and a few set of measure are examined to investigate the applicability to the problems of urban environment change detection. using remote sensing data. For this purpose, the following strategies are established.:

1) Classify the ground cover types of urban areas based on spectral properties of objects or classes using Landsat TM data, which should be less affected by radiometric environment changes such as atmospheric environment and seasonal sun illumination.
2) Identify major groundcover types that forms urban areas such as high-density areas, and residential area.
3) Define boundaries of urban areas systematically.
4) Quantify the spatial distribution of the ground cover types, i.e., estimate the measures of landscape indices.

As there are more than hundreds of measures proposed in landscape ecology, it is difficult to make a short list of most appropriate measure for urban environment analysis. Thus, in this study, a few measures are to be investigated. They are: population of each ground cover type in a spatial window, entropy measure to quantify inequality of class distribution in those windows, and fractal dimension of ground cover classes for shape –oriented quantities.

III. Data Set

The data set for this experiment are as followed.
Landsat TM images acquired on:
(1) January 23,1985
(2) January 17,1995
(3) November 14,1999

These Images cover Kanto area including Tokyo and Greater Tokyo metropolitan area. The reason why the winter data sets were chosen is that it is much easier to find the could-free data set in this season.

These images are trimmed and registered to cover the target area for our study. Figure 1. Illustrates an sub-image of the study area for 1995. The data set of 1999 includes some clouds, which were removed by interactive operation, but the result is not perfect

IV. Spectral Classification

The first task is to classify the TM data into ground cover types of urban area more stable against radiometric environment differences for temporal data set for 3 years. As there is no operational atmospheric correction methods available, it is difficult to expect that each data set would have been well normalized in terms of atmospheric and sun illumination condition.

As one alternative, unsupervised classification methods were used as their pre-analysis of urban environment to identify base ground cover types for urban areas.

For a give data set, several steps of single-pass-unsupervised methods are applied to determine the optimum number of initial clusters that is required for ISODATA type unsupervised clustering. In this experiment, 25 initial clusters are set for the data set of 1985 and 1995, 26 clusters for 1999 to take in account for the cloud mask class. As the major groundcovers might not be changed very much during the period of investigation, the proportion of each cluster also would show a similar distribution .

The next step is to identify the ground cover types

Cluster #	MODVI		
1	1985	1995	1999
2	0.0	-0.1	0.2
3	0.1	0.0	0.1
4	0.0	0.1	0.3
5	0.1	-0.1	0.0
6	0.1	0.2	0.0
7	0.2	0.1	0.1
8	0.0	0.2	0.3
9	0.1	0.0	**0.6**
10	0.2	0.2	**0.7**
11	0.2	0.1	0.6
12	0.1	0.1	**0.4**
13	0.2	0.2	-0.1
14	0.2	0.2	0.0
15	0.2	0.0	0.1
16	0.1	0.3	0.6
17	0.3	0.2	0.1
18	0.1	**0.4**	0.3
19	**0.4**	0.1	**0.8**
20	0.1	0.2	0.1
21	**0.6**	0.1	-0.5
22	0.1	**0.7**	0.1
23	0.1	0.1	0.2
24	0.2	0.3	0.1
25	-0.2	0.0	0.2

Table 1. Modified Vegetation Indices for 25 Clusters

correspond to each cluster. This procedure is ordinary conducted interactive way by the image analysis operators. In this experiment, each cluster is evaluated in terms of brightness of groundcover types and modified vegetation indices.: the components of TM visible band, i.e., Band 1, Band 2 and Bands 3 for each cluster are averaged and the results is defined as the brightness of the clusters, and the modified vegetation index for each cluster is estimated from the following equation similar to the conventional vegetation indices.

$$MODVI = \frac{(Clust_{k4} - Clust_{w,4}) - (Clust_{k,3} - Clust_{w,3})}{(Clust_{k4} - Clust_{w,4}) + (Clust_{k3} - Clust_{w,3})}$$

Here, $Clust_{ki}$ stands for the spectral component of TM band i of Cluster k and Cluster W is the cluster of water class.

The modified vegetation index is less affected by the atmospheric quality changes and seasonal sun illumination angle differences. Therefore, this measure is more appropriate for change detection for remote sensing..(See table 1.) The clusters with modified vegetation indices (MODVI) larger than 0.4 are vegetation covers. The population for bright or brighter clusters are generally for each years., and they are mostly bright roof tops of big buildings , pits or gravel field. Thus, the total numbers of pixels (or area sizes) is small compared with the image size.

It has been identified that the urban areas and down town area are consisted of darker clusters and brighter clusters are located mostly in agriculture fields, golf courses, grassland

Thus, it might be possible to exclude them as the base ground cover types for our study of urban environment analysis.

Among the cluster based groundcovers types, it has been identified that the urban areas are composed with darker objects, i.e., cluster 20 or cluster of higher numbers. Those are: high-density down buildings and express ways, dense-low-story-residential areas including small buildings and residential areas. Some dense vegetation areas and water bodies are of course mixed in those areas. Unfortunately, the dark cluster and brighter clusters with higher MODVI values are inconsistent with those clusters in 1985 and1995.

This might be caused by the fact that the 1999 data set is acquired in different season. The mixing ratio between building shadow are and building roof tops must be very different and there are more vegetated area in November. Thus , hereafter, the data set of 1999 is discarded in this experiment.

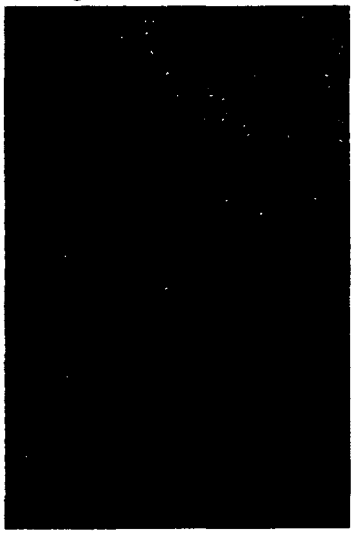

Figure 2. Thematic Map from Clustered result.(1995)

Figure 2 shows the thematic map for 1995 extracted by the procedure describe in above.

Before moving to the task to estimate the landscape index measures, a method to automate delineation of urban area is investigated .In many cases, the classes of urban landscape are presented in rectangle regions or administrative districts. In this experiment, an alternative region is defined using an automated approach as follows.

: Using the location of man-made features such as high-density down town areas and residential areas, those areas are smoothed applying conventional 2 dimensional convolution with 5x5 windows. This process is required to reduce the miss-registration or mixed pixels on the boundaries between different spectral classes. The result images are cut off with a threshold of 0.75,that is, a single urban class occupies 75% of pixels in a window. This procedure contributes also to eliminate small blobs consisted of similar spectral of urban elements. With this result images, morphological dilation operation is applied with a structure element of suitable size that might be considered as the range or distance of urban activities. With this experiment, size of 13x 13 window is used, i.e., about 500mx500m. This will be acceptable as a distance for human settlement, excluding the range of modern transportation system.

The following figure 3 illustrates the Tokyo metropolitan area delineated by the procedure described above. from the Landsat TM data of 1985 and 1995.

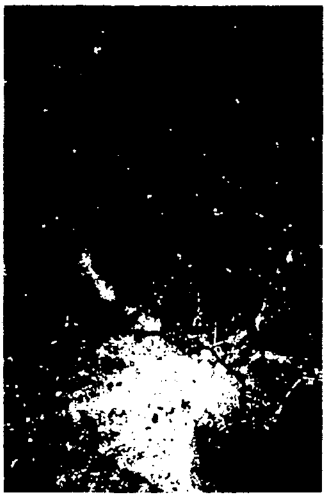

Figure 3..The urban area (or mask) defined by the TM Data

V. Landscape index estimation

Landscape indices by definition deals with the indices of landscapes. There are many different interpretations of the term "landscape." Definitions of landscape include an area of land containing a set of mosaic of patches or landscape elements, which could correspond to the ground cove classes. Defined landscape as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in similar form throughout.

Population of Classes in the neighbor.

One of the simplest measure for a landscape index is to estimate the number of a specified in a spatial window that define the neighbor region. This measare is expressed in the following equation:

$$Pop_k = \sum\sum(Nk_{i,j})$$

Here, *Popk* is the number of class k in a spatial window, and Hki,j indicates the existence of class k in the window coordinate, *i* and *j*.

The window sizes are, 5.x5, 9x9x and 13x13 and the shapes of the windows are approximated to circles of the same diameters as much as possible by cutting the corner of the windows. Figure 4 show the population of each classes in 1985 and 1995 with different sizes of the windows.

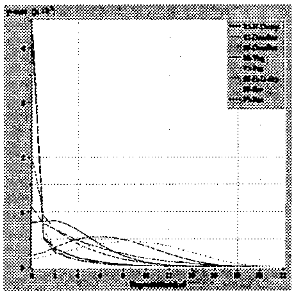

Figure 4A. Class population changes between 19985 an 1995 with a window of size 5x5

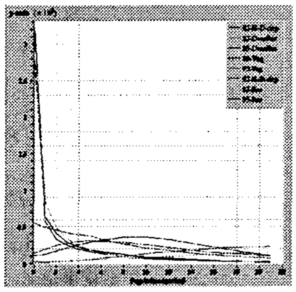

Figure 4B. Class population changes between 19985 an 1995 with a window of size 5x5

It is observed that the class of residential-commercial area is shifted to the higher number. That is, the residential–commercial area has more same classes in its neighbor in 1995. It is also observed that the dependency to the window sizes area minor.

Entropy

In order to describe how unequally the classes are distributed in spatial windows, or how equally the classes reside in the window., a measure of entropy is applied.

The entropy measure is defined by the following equation.

$$Ent = -\sum_{i=0}^{n} P_i Log(P)_i$$

Here, P_I means the probability of a class *i* in a vicinity window. It is observed that the distributions of the small window, 5x5, show more fluctuated and wider distribution, while distributions with other windows of 9x9 and 13x13 have similar shape and the location of the peaks are overlapped. In other words, the window size for Tokyo can be chosen as 9x9x,ie. 270mx270m neighbor-window.

Figure 5 illustrates the comparison of the entropy changes in Tokyo urban area for 1985 and 1995. The entropy distributions for 1985 locates lower than that for 1995, and show broader width.
This can be interpreted that there appeared more districts or zones which have more unequal areas(or textured area) emerged between 1985 and 1995.

Figure 6 illustrates a entropy image for 1995.The high density areas shows higher entropy.

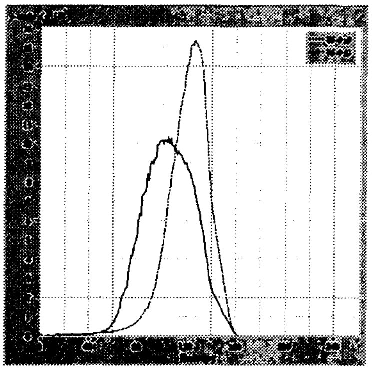

Figure 5. Entropy change between 1985 and 1995 with 9x9window.

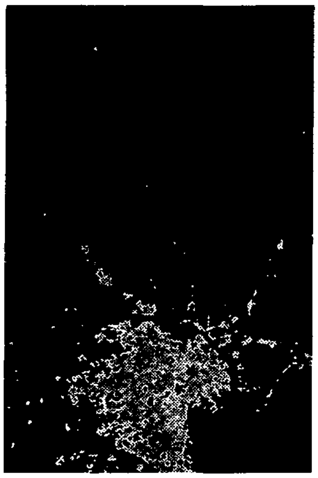

Figure 6.Entropy of 1995

Fractal Measure

Another measure to quantify the shapes of classes : some objects appear as prolonged or line like objects and others appear as the landscape indices is to measure the fractal dimensions of groundcover type objects. For examples, line-like patterns like roads, high ways small rivers have to have fractal dimensions between 1.0 and less than 2, if the spatial resolution is small enough to detect those features.
In this experiment, the following method is used to estimated fractal dimensions for each groundcover types: vegetation, residential area, mixed areas of residential and commercial areas, and high density urban areas.

$$FD = \frac{1}{2} Log(S_i / S_j) / Log(i / j)$$

Here S_i (or Sj) is s a sum of the pixel values in a window of size i(or j). With this experiment, 5 x5 and 9x9 windows are combined for fractal estimation. I.e., if the

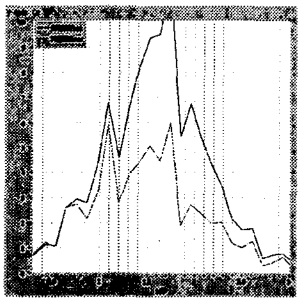

Figure 7A. Fractal dimension distribution of the high-density areas.

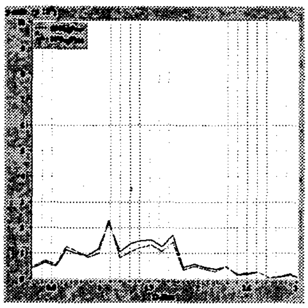

Figure 7B Fractal Dimension distribution of Vegetation

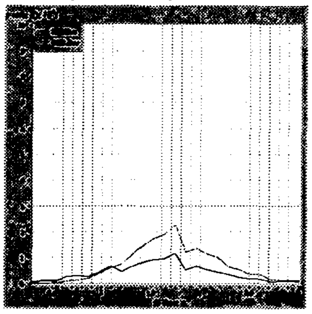

Figure 7C Fractal dimension distribution of dense residential areas.

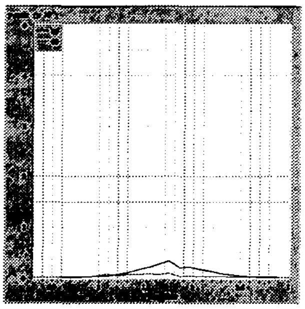

Figure 7D. Fractal dimension distribution of residential areas..

inside of the 9x 9 window s well as that of the
A single class or same values occupy 5x5 window, then the area of 9x9 window stands for an area-like object.

The spatial characteristics of .the urban classes are examined, and they are shown in Figure 7A, 7B.7C and 7D.As seen in Figure 7D, the distribution of the fractal dimension of residential area has shifted to higher value from 1985 to 1995. This indicates that more area-like residential pixels have increased. This might be consequence of parcel sizes of residential areas became to be smaller..

VIII. Discussion and Conclusion

1) As shown in above, spectral classes are reasonably well extracted from TM data set of different years, without robust atmospheric correction1, if the data set is acquired at similar sun illumination conditions. It is also attempted to compare the urban environment of different

years. Instead of direct comparison among the spectral classes derived form remote sensing data.. Based on these measures, it has been shown that Tokyo metropolitan area was expanded , especially to raise the surface roughness. This can be concluded from the fact that the high density areas of darker objects,
i.e., pixels mixed with tall buildings, was expanded in the center of Tokyo and along main roads or new rail ways.

It is also observed that the core area of Tokyo, mostly mixed with houses and small buildings, was expanded during the period between 1980s and 1990s.
As the processing procedure in this experiment requires much less operator intervention, it is possible to automate the analysis, upon completion of validation test of those results.

2) In this experiment only a few spectral classes are examined with a few set of landscape index estimation. More spectral classes could be extracted from TM data. But, most of the classes not used for this analysis belong to the pixels spectrally mixed in more complex manner.. Therefore there were more difficulty to identify the label of classes in consistent with seasonal changed classes
3) Treatment of the mixed pixels should be imporved more.
4) Boundaries of Urban area could be extracated automaically if they are intrested in more urban ecology..
5) Landsacpe Indices are useful to qauntify the spatial characaterisitcs of ground cover distribution.
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IX. Future Study

More study is required to obtain robust and reliable classification methods against seasonal changes of remotely sensed data. Furthermore, selection of landscape indices for urban environment will be another important task. With this task, it is necessary to define again the concept of urban environment, in what sense, and for what.

X. Acknowledgement

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