Evaluation of Some Spectral and Spatial Features of Satellite Images Using Airborne MSS Data for the Analysis of Urban Area

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Abstract

The authors conducted some simulation experiments using airborne multispectral scanner (MSS) data for the purpose of the evaluation of effectiveness of several spectral and spatial features obtained from various satellite images at the test site of urban areas. The ground resolution of pseudo-satellite data generated by averaging the original airborne MSS data with 5 meters resolution was 10, 20, 30, 50 and 80 meters which corresponds to SPOT-HRV, Landsat-TM, MOS-1-MESSR and Landsat-MSS respectively. The simulation experiments using the pseudo-satellite data were conducted on the following ground feature analyses.

(1) Direct extraction of vegetation cover rate (VCR) within one pixel size using vegetation index (VI) obtained from visible and near-infrared spectral data.

(2) Classification of urban structures (low-rise vs. high-rise and low-dense vs. high-dense) using local density average (LDA) and local density variation (LDV) of multispectral images.

As the result of the experiment(1), it was proved that high correlation over 0.9 between VCR and VI can be obtained all of the resolution range from 20 to 80 meters. From the experiment(2), LDV combined with LDA was proved to show the highest classification performance at the ground resolution of 20 or 30 meters.

1. Introduction

By Landsat-TM and SPOT-HRV data, relatively high resolution satellite images have become available for land cover analysis. The authors conducted some simulation experiments using airborne multispectral scanner (MSS) data for the verification of new possibility of land cover analysis at urbanized areas using those high resolution satellite data. As the ground resolution of the airborne MSS data is 5 meters, the pseudo-satellite data of the ground resolutions of 10, 20, 30, 50 and 80 meters can be available for the simulation, which resolutions correspond to those of SPOT-HRV (panchromatic and multispectral), Landsat-TM, MOS-1-MESSR and Landsat-MSS respectively.

The following two kind of ground features were selected for the evaluation of applicability of satellite images.

(1) Vegetation cover rate (VCR) within the pixel size of satellite images at the urban areas.

(2) Urban structures representing low-rise vs. high-rise and low-dense vs. high-dense on the distribution of houses or buildings.

For the estimation of VCR, the vegetation index (VI) values represented by normalized difference or bi-band ratio of visible and near-infrared data were used as the spectral features. For the classification of urban structures, the local density average (LDA) and the local density variation (LDV) of multispectral images were used as the spatial features as well as the spectral features.

The test site was the central part of Tokyo metropolitan area which covers the rectangular area of 20 kilometers by 4 kilometers. The airborne MSS data was taken on May 23th in 1982, at the altitude of 2,000 meters.

2. Estimation of Vegetation Cover Rate within One Pixel

2.1 Experimental Method

The flow chart of the simulation for evaluation of estimation accuracy of vegetation cover rate within the pixel size of satellite images by the vegetation index values is shown in Fig.1. The labeling of vegetation or non-vegetation for individual pixels of the original airborne MSS data was performed by clustering techniques, and the labeled data are compiled to the mesh data which represent the vegetation cover rate (VCR) within the four kind of pixel sizes of 20, 30, 50 and 80 meters. The original airborne MSS data are averaged into the pseudo-satellite data which have the same mesh sizes as the vegetation cover rate data, and the vegetation index (VI) values are calculated for every pseudo-satellite image pixels. Then the regression analyses are conducted between the VCR mesh data and the VI mesh data.

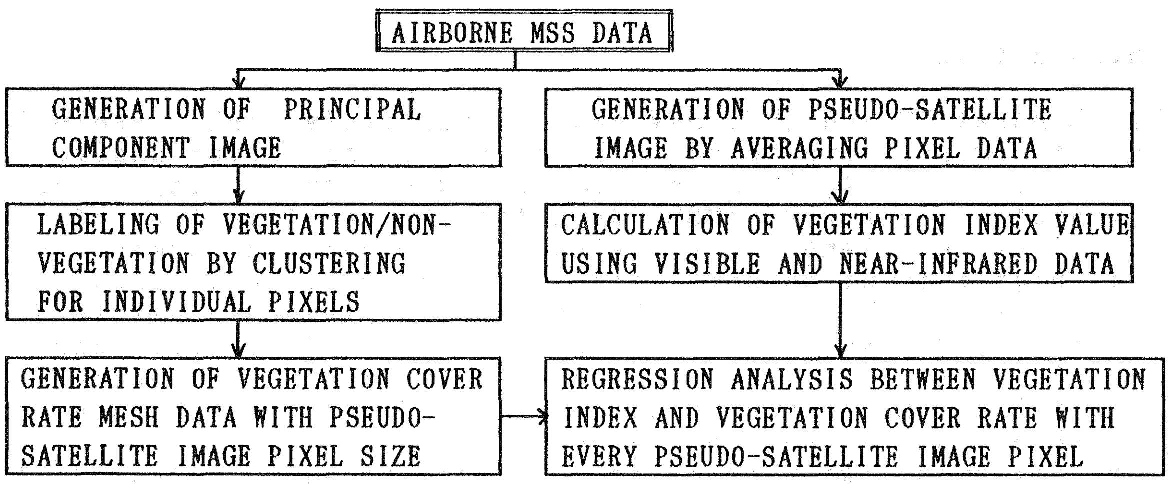


Fig.1 Flow chart of simulation experiment for the estimation of vegetation cover rate within one pixel size of satellite images using vegetation index as a spectral feature.

The following two spectral features were used as vegetation index (VI) value.

(1) Bi-band ratio : BR(IR,R)

$$BR(IR,\ R)=M\times\frac{DC(IR)-OF(IR)}{DC(R)-OF(R)}$$

where,

DC(IR): Digital count value of near-infrared region.
DC(R) : Digital count value of visible-red region.
OF(IR),OF(R): Digital count value corresponding to path radiance for near-infrared and visible-red region.
M : Scale factor (M=20)

(2) Normalized difference : ND(IR,R)

$$ND(IR,\ R)=M\times\frac{DC(IR)-DC(R)}{DC(IR)+DC(R)}+Oz$$

where,

DC(IR),DC(R) and M are same as (1) (M=100)
Oz : Zero offset (Oz=20)

The channel 7 (0.66 − 0.7 μm) and channel 9 (0.77 − 0.86 μm) from the airborne MSS data were used as the visible-red and near-infrared spectral data.

2.2 Experimental Results

Table.1 shows the results of linear regression between VI and VCR for the pixel sizes of 20, 30, 50 and 80 meters. The scatter diagrams for VCR vs. BR(IR,R) and VCR vs. ND(IR,R) are shown in Fig.2 and the regression lines are illustrated as dotted lines in Fig.2. In Table.1 relatively high correlations are obtained for every pixel size from 20 to 80 meters. In the case of BR(IR,R), non-linear relation between VCR and BR(IR,R) is dominant in Fig.2, which causes relative low correlation values compared with those for ND(IR,R).

For taking account of this non-linearity, cumulative normal distribution (CND) function was introduced for the regression.

$$Y=b_0+b_1F(X\,;\mu,\sigma)$$

where, Y is VCR and X is BR(IR,R) or ND(IR,R) and $F(X\,;\mu,\sigma)$ is the CND function formulated as follows,

$$F(X\,;\mu,\sigma)=\frac{1}{\sqrt{2\pi}\sigma}\int_{-\infty}^{x}e^{-(x-\mu)^2/2\sigma^2}dx$$

where, μ, σ are mean value and standard deviation of X respectively.

Table.2 shows the regression results using above CND function, in which higher correlation values are obtained compared with the results of Table.1 at every pixel size for both BR(IR,R) and ND(IR,R). The regression curves for CND regression are illustrated by solid curves in Fig.2, which give more reasonable approximation for the relation between VCR and VI.

From these simulation experiments, the vegetation cover rate within the pixel sizes from 20 to 80 meters are proved to be estimated by the vegetation index values (BR(IR,R) or ND(IR,R)) at urbanized areas. This possibility is considered to contribute for the application of various satellite images such as Landsat-TM/MSS, MOS-1-MESSR and SPOT-HRV for the survey of vegetation condition at urbanized areas.

Table. 1 Correlation coefficient and residual error (RMS) by linear regression between vegetation index and vegetation cover rate within one pixel size.

PIXEL SIZE(m)	VEGETATION INDEX OF INDIVIDUAL PIXELS			
	BR(IR, R)		ND(IR, R)	
	CORR. COEF.	RES. ERR. (%)	CORR. COEF.	RES. ERR. (%)
80 X 80	0.832	11.3	0.961	5.6
50 X 50	0.814	13.1	0.953	6.7
30 X 30	0.818	14.6	0.942	8.5
20 X 20	0.809	16.5	0.929	10.4

Table. 2 Correlation coefficient and residual error(RMS) by cumulative normal distribution (CND) regression between vegetation index and vegetation cover rate within one pixel size.

PIXEL SIZE(m)	VEGETATION INDEX OF INDIVIDUAL PIXELS			
	BR(IR, R)		ND(IR, R)	
	CORR. COEF.	RES. ERR. (%)	CORR. COEF.	RES. ERR. (%)
80 X 80	0.942	6.8	0.969	5.0
50 X 50	0.931	8.2	0.964	6.0
30 X 30	0.932	9.2	0.959	7.2
20 X 20	0.926	10.6	0.953	8.5

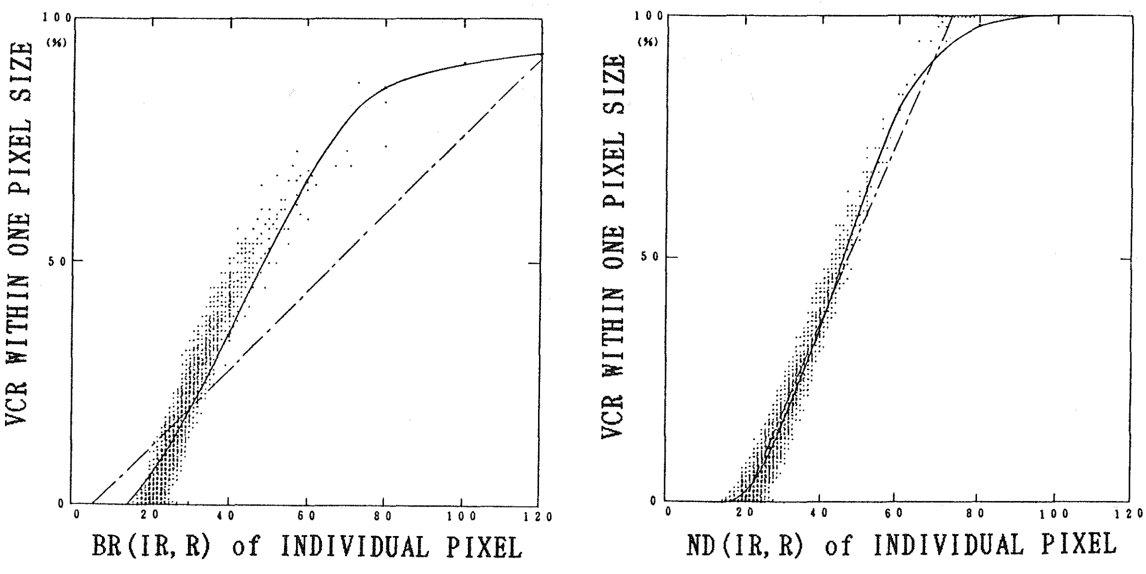


Fig. 2 Scatter diagrams for the relations between vegetation cover rate (VCR) within one pixel size and vegetation index values by BR(IR, R) and ND(IR, R). The dotted lines are regression lines by linear regression and the solid curves are regression curves by CND regression.

3. Classification of Urban Structures Using Combined Features of Spatial and Spectral Information.

3.1 Experimental Method

The following two kind of features which combine spatial information with spectral information are used for the classification of urban structures,

(1) Local density average (LDA)

$Aij(k)$: The average density value of n x n surrounding pixels in channel k.

(2) Local density variation (LDV)

$Vij(k) = (Sij(k)/Aij(k)) \times M$

$Sij(k)$: The standard deviation of density of n x n surrounding pixels in channel k.

M : Scale factor (M=100)

LDA represents the average spectral characteristics within a spatial window (n x n) and takes place of the spectral information of individual pixels. The window size of 150 and 250 meters square on the ground were used for the spatial window in which LDA and LDV are calculated.

The spectral data used were channel 7 (0.66 – 0.70 μm) and channel 9 (0.77 – 0.86 μm) from the airborne MSS data same as those used for the previous simulation of the estimation of vegetation cover rate. Thus the combined data of LDA and LDV are similar to four channel multispectral data. The range of the pixel size of the pseudo-satellite data used for the classification was 5 meters (original pixel size), 10, 20, 30, 50 and 80 meters, the latter five kind of data were generated by averaging the original airborne MSS data.

Table.3 shows six kind of classification categories about the difference of urban structure. The training areas and the evaluation areas were individually selected for each of the categories using aerial photographs, and the classification accuracies were evaluated independently for the training areas and the evaluation areas. The maximum likelihood classifier was used for the classification procedure. The classification cases were the following five cases.

(1) Using only spectral information of individual pixels (Case-1).

(2) Using LDA instead of Case-1 (Case-2 for 150m window size and Case-3 for 250m window size).

(3) Using both of LDA and LDV (Case-4 for 150m window and Case-5 for 250m window).

Table.3 Classification categories for discrimination of urban structures.

CATEGORY	CHARACTERISTICS OF URBAN STRUCTURES
1. VERY HIGH-RISE	Composed from very high-rise buildings above 30 floors.
2. HIGH-RISE	Composed from high-rise buildings above 10 floors.
3. MIDDLE-RISE & HIGH-DENSE	Composed from densely built-up middle-rise buildings from 3 to 8 floors.
4. MIDDLE-RISE & LOW-DENSE	Composed from middle-rise buildings but the density is lower than that of category 3.
5. LOW-RISE & HIGH-DENSE	Composed from densely built-up low-rise houses below 2 floors.
6. LOW-RISE & LOW-DENSE	Composed from low-rise houses but the density is lower than that of category 5 and vegetation cover is relatively higher than those of other categories.

3.2 Experimental Results

Table.4 shows the results of classification accuracy for the five classification cases (Case-1 to Case-5) and six kind of pixel sizes (5 to 80 meters) in the training areas and the evaluation areas. In the training areas, the cases for the use of LDA or both LDA and LDV show higher accuracy than those of Case-1 for every pixel size. In Case-1 it is clearly indicated that the higher resolution results in the lower classification accuracy, which suggests the limitation of pixel-wise spectral information for the analysis of urban structures.

In the evaluation areas, the accuracy level for every case is lower than that in the training areas, which suggests the representativeness of the training areas is not sufficient for the classification categories shown in Table.3. In Table.4 accuracy improvement is obtained by the use of LDA or both of LDA and LDV for the pixel sizes smaller than 30 meters. In addition, the highest accuracy is obtained at the pixel size of 30 meters for Case-4 and at the pixel size of 20 meters for Case-5. This result suggests that the effectiveness of spatial information varies by the ground resolution of the satellite images and also that there is optimal resolution range for the use of LDV.

Fig.3 shows the characteristics of LDA and LDV for six categories at the pixel size of 5, 20 and 80 meters. It is clearly shown that the maximum difference of LDV characteristics for every category appears at the pixel size of 20 meters while LDA characteristics for three kind of pixel sizes are almost constant.

From these experiments, it is proved that the combined use of spatial information and spectral information gives the improvement of classification accuracy if the ground resolution is higher than 30 meters. The most optimal case for the classification accuracy is the use of LDV combined with LDA for the ground resolution of 20 or 30 meters. This resolution range corresponds to that of SPOT-HRV (multispectral) and Landsdat-TM data and these experimental results are considered to give the important evidence for the effectiveness of high resolution satellite images such as Landsat-TM and SPOT-HRV.

4. Discussion

The relation between the effectiveness of the features and the ground resolution of the satellite images is rather different in above two kind of simulation experiments. In the case of the estimation of vegetation cover rate, the spectral feature represented as the vegetation index is very "strong" for the variation of ground resolution. This characteristics of vegetation index seems to come out from the clear contrast of the spectra in visible and near-infrared region between vegetation and non-vegetation. Especially at urbanized areas, they are almost composed from artificial materials (houses,buildings and road) and vegetation, which emphasizes the contrast of the spectra of vegetation/non-vegetation.

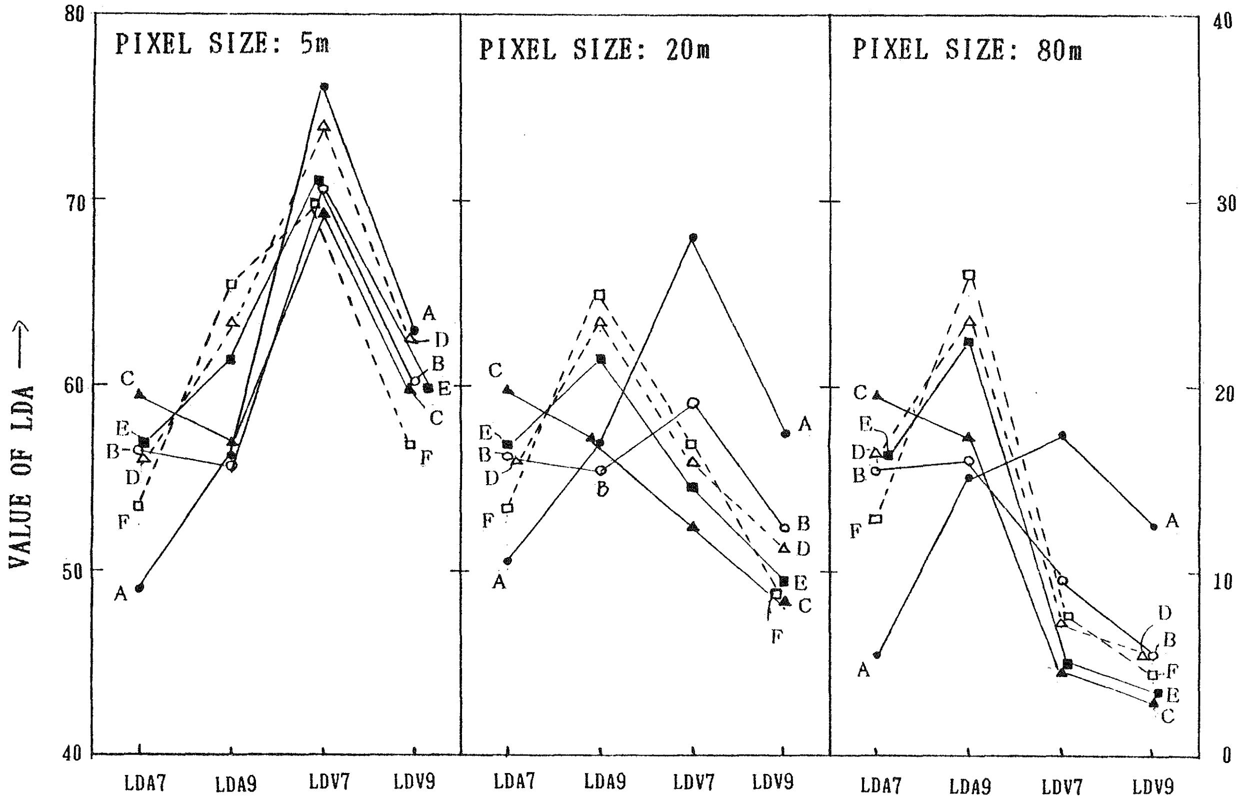
Table. 4 Classification accuracy (%) for five classification cases (Case-1 to 5) and six kind of pixel sizes from 5 to 80 meters in the training areas and and the evaluation areas.

< TRAINING AREAS >

PIXEL SIZE(m)	PIXEL-WISE SPECTRA (CASE-1)	USE OF ONLY LDA 150m-WD (CASE-2)	250m-WD (CASE-3)	AVERAGE (C-2+3)	USE OF BOTH LDA AND LDV 150m-WD (CASE-4)	250m-WD (CASE-5)	AVERAGE (C-4+5)
5 X 5	32.8	80.7	90.0	85.4	90.0	94.3	92.2
10 X 10	37.1	80.0	89.4	84.7	93.3	96.0	94.7
20 X 20	47.5	82.0	87.4	84.7	93.7	95.0	94.4
30 X 30	51.0	81.7	87.7	84.7	94.7	95.0	94.4
50 X 50	60.7	78.0	90.7	84.4	89.0	95.7	92.4
80 X 80	66.5	81.4	87.4	84.4	89.7	95.3	92.5

< EVALUATION AREAS >

PIXEL SIZE(m)	PIXEL-WISE SPECTRA (CASE-1)	USE OF ONLY LDA 150m-WD (CASE-2)	250m-WD (CASE-3)	AVERAGE (C-2+3)	USE OF BOTH LDA AND LDV 150m-WD (CASE-4)	250m-WD (CASE-5)	AVERAGE (C-4+5)
5 X 5	20.3	58.0	64.0	61.0	41.7	41.7	41.7
10 X 10	27.7	59.0	62.0	60.5	55.7	62.0	58.9
20 X 20	41.0	63.4	69.4	66.4	70.3	74.3	72.3
30 X 30	41.3	67.4	63.7	65.6	72.7	68.3	70.5
50 X 50	54.7	51.7	55.7	53.7	56.3	51.0	53.7
80 X 80	46.3	55.3	49.7	52.5	57.0	50.3	53.7



A:VERY HIGH-RISE B:HIGH-RISE C:MIDDLE-RISE & HIGH-DENSE
D:MIDDLE-RISE & LOW-DENSE E:LOW-RISE & HIGH-DENSE F:LOW-RISE & LOW-DENSE

Fig. 3 LDA and LDV characteristics for six kind of categories at the pixel sizes of 5, 20 and 80 meters. The window size is 250 meters on the ground for every case.

In the case of the discrimination of urban structures, The spatial feature is rather sensitive for the variation of ground resolution. The local density variation (LDV) is considered to be related to the spatial variation of density due to the distribution of houses, buildings, roads and open spaces. The existence of optimal range of ground resolution for LDV seems to come out from the information rate between regular distribution of density due to ground pattern and random density distribution due to noise. The higher resolution above the optimal range is considered to increase the noisy information on the spatial features represented by LDV.

5. Conclusion

The authors conducted two kind of simulation experiments using airborne MSS data, for the purpose of the evaluation of the effectiveness of some spectral and spatial features of satellite images. The first experiment verified the effectiveness of vegetation index by visible and near-infrared spectral data for the estimation of vegetation cover rate within the pixel size of various satellite images such as Landsat-TM/MSS, MOS-1-MESSR and SPOT-HRV. The second experiment verified the effectiveness of the combined features of spectral and spatial information represented by LDA and LDV for the classification of urban structures, although this effectiveness depends on the ground resolution and the optimal range of the resolution is from 20 to 30 meters.

This kind of simulation experiment using airborne data seems to be very useful and also very important in order to verify the effectiveness of various kind of spectral and spatial features extracted from various satellite images.

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