Synergic Effect of using the Optical and Radar Image Data for the Land Cover Classification in Coastal Region

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Abstract: This study aimed to analyze the effect of combined optical and radar image for the land cover classification in coastal region. The study area, Gyeonggi Bay area has one of the largest tidal ranges and has frequent land cover changes due to the several reclamations and rather intensive land uses. Ten land cover types were classified using several datasets of combining Landsat ETM+ and RADARSAT imagery. The synergic effects of the merged datasets were analyzed by both visual interpretation and an ordinary supervised classification. The merged optical and SAR datasets provided better discrimination among the land cover classes in the coastal area. The overall classification accuracy of merged datasets was improved to 86.5% as compared to 78% accuracy of using ETM+ only.
Keywords: synergic effect, image fusion, optical and SAR, coastal land cover, PCA, image classification, separability

1. Introduction

The multi-sensor image data were one of main interest to analyze earth surface features since both optical and SAR data became available. Previous studies using both optical and SAR data have shown that the classification accuracies were improved as compared to using only one dataset. The classification accuracy of land cover/use using combined Landsat TM and RADARSAT was higher than using one sensor image in [1],[3],[4],[12]. Multi-sensor images were also known to be effective in the classification of forest species and the characterization of forest stand structure in [2],[6],[8],[9]. The synergic effect of multi-sensor images was also reported in the cases of geological studies and DEM generation in [5].

Although the classification accuracy was improved with combined optical and SAR data in many previous studies, their classifications were based on relatively simple land cover classes that can also be classified using only multispectral data with moderate accuracy. This study concerned the classification of rather complex land cover categories, which are spectrally and spatially similar, in the coastal region. This study aimed to test the synergic effect of multi-sensor approach for the land cover/use classification of the coastal region.

2. Study Area

The study area covers about 3,000km^2 in Gyeonggi Bay, which includes the Incheon and other several islands of Ganghwa, Gyodong, and Youngjong.

Gyeonggi Bay is well known for the high tidal range. The tidal difference between low and high tides is close to 9 meters and, therefore, the huge tidal flat area serves very unique and important functions for the the fishery industry as well as the coastal ecosystem. However, due to the rapid industrialization and population growth in Incheon and Seoul metropolitan area, the study area has been susceptible for land development. In recent years, large scale land reclamation works have been completed to build the Incheon International Airport and Si-hwa Industrial Complex. To preserve the environmental health and to maintain appropriate land use practices, it is necessary to have an effective method for the periodic monitoring of frequent land cover/use changes in this region.

Using the reference data related to the land use/cover statistics in the study area, we defined ten land cover classes. Five cover types are mainly for the area near the coast line and the other five classes are for the inland area. Table 1 shows the list of ten cover type classes defined for this study.

Table1. Ten land cover classes of study area

Land cover	Specifications
Clear water	Clear river, ocean, salt farm and fish farm
Turbid water	Mud river, ocean, salt farm and fish farm
Wet tidal flat	Exposed wet land by difference of flux and reflux
Dry tidal flat	Partly filled area and exposed tidal flat at the lowest tide on every time
Halophytes (Salty plants)	Including species of S. japonica Makino, S. martima Dum., et al. and distributing at the tidal flat, dunes, abandoned salt farms [10]
Bare soil	Flat bare soil and quarry and paved land
Urban	Including buildings and roads
Forest	Including deciduous and conifer forest
Paddy	Flat crop land
Grass	Grass land, meadow, golf course and grave

3. Methods

Both Landsat ETM+ and RADARSAT SAR data were obtained during the summer of 1999 to minimize the seasonal variation of vegetation features. Seven bands of ETM+ data were acquired on June 30, 1999 and C-HH SAR data were acquired on August 4, 1999. To reduce the overweighing problem of seven bands of ETM+ data over a single band of SAR data, we used only three bands of red (band3), NIR (band4), and MIR (band5) ETM+ data. As can be seen the correlation matrix among the ETM+ data, the other bands shows high correlation with the selected band (Table2).

Table2. Correlation Matrix of Landsat ETM+ 6bands

Correlation Matrix						
	B1	B2	B3	B4	B5	B7
Band1	1	-	-	-	-	-
Band2	0.92	1	-	-	-	-
Band3	0.85	0.97	1	-	-	-
Band4	-0.13	0.15	0.2	1	-	-
Band5	0.21	0.49	0.56	0.86	1	-
Band7	0.44	0.67	0.74	0.65	0.94	1

Before the classification, the SAR data were processed by speckle removal filters by the Lee's sigma filter [7]. The speckle reduced SAR image was then registered into the Landsat ETM+ image. To test the synergic effect of using both optical and SAR data, we used several datasets of 1) a single sensor data (3-bands ETM+, 1-band SAR), 2) 4-bands dataset combining both data, 3) fused datasets by principal component analysis (PCA) methods. PCA transformation was applied to the four band dataset and the first three principal components (which explained the 98.3% of total variances) were used for the final analysis.

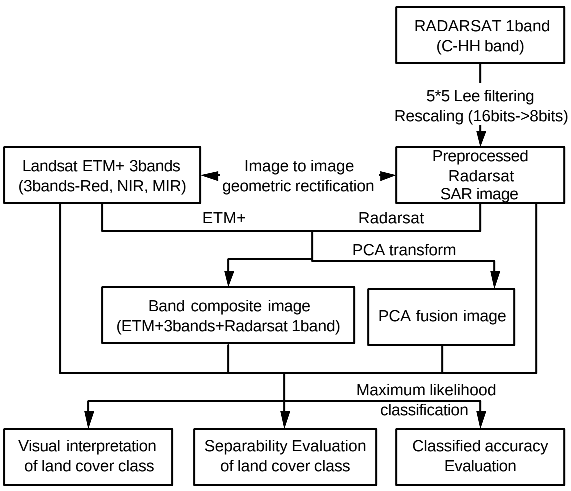

Figure 1. Flow chart of processing and analysis

The synergic effects of the fused datasets were analyzed by both qualitative visual interpretation and quantitative methods. The ten cover type classes were visually interpreted from both a single sensor image and the fused color composites. For the quantitative analysis, spectral separability among the ten cover type classes was compared. The spectral separability used for this study was the transformed divergence, as shown in Eq. 1 [11].

$$TD_{ij} = 2000\left(1 - \exp\left(\frac{-D_{ij}}{8}\right)\right) \qquad (1)$$

$$D_{ij} = \frac{1}{2}tr\left((c_i - c_j)(c_i^{-1} - c_j^{-1})\right) + \frac{1}{2}tr\left((c_i^{-1} - c_j^{-1})(m_i - m_j)(m_i - m_j)^T\right)$$

i, j: classes
C_i: the covariance matrix of signaure i
μ_i: Mean vector of signature I
tr: Trace function (Matrix algebra)
T: transposition function

The four datasets were classified using a supervised maximum likelihood method. The same training fields that were defined by using the high resolution satellite image, local land use map, and on-site visit, were applied for the four datasets. To assess the classification accuracy, additional test fields were also defined.

4. Results

1) Visual interpretation

The inland cover types were well separated by the visual interpretation on the RGB composite image of the three ETM+ bands. However, the coastal cover types (such as turbid water, wetness of tidal flat, and halophytes) were not very obvious on ETM+ color composite. The single black-and-white Radarsat SAR image was not effective to differentiate the land cover types. However, a certain surface features (such as wetness of tidal flat and halophytes) can be seen from the texture variation on the SAR image. The color composite of two ETM+ band and one SAR band showed the better discrimination of ten cover types although the interpretability varies by the band combination of ETM+ and SAR data. The color composite of three principal components showed the best interpretability of both inland cover types and coastal cover types.

2) Separability

To analyze the spectral separabilty of ten land covers in all four datasets, we used the transformed divergence value. All datasets, except the SAR data, showed the average transformed divergence value of over 1900. From the analysis on the separability between any two classes, the merged datasets revealed higher separability than the ETM+ dataset. Table 3 showed the separability of a few pairs of two classes that are very similar spectral characteristics. The spectral separabilities were not much different between the four-band combined dataset and the PCA fused dataset.

Table 3. Transformed divergence separability between land classes (If transformed divergence value was below than 1700, this class couldn' t be separated)

Class-Class	ETM+	SAR	Band com.	PCA
Tidal flat - Halophytes	1987.2	312.5	1995.8	1994.1
Dry tidal flat - Halophytes	1991.9	1816.0	1995.9	1994.8
Dry tidal flat – Urban	1283.4	363.0	1618.5	1617.3
Grass – Paddy	1439.5	802.6	1642.7	1640.3
Forest - Paddy	1584.2	1064.5	1816.2	1814.9

3) Classification accuracy

Figure 2 shows the classified map using the PCA fused dataset. We felt comfortable on this classification result as compared with other classified maps using the other datasets. The classification accuracy assessed by the a set of predefined test fields showed that the overall classification accuracy between two combined dataset and one sensor dataset, the overall accuracies of fusion datasets were 86.5% as compared to the 78% with the ETM+ data only (Table 4). The synergic effect of using both optical and SAR data was particularly obvious for the classification of certain cover types. The classification accuracies of clear water, turbid water, halophytes, and rice paddy were notably improved. On the other hands, some other cover types (dry tidal flat and grass) showed lower accuracies with the combined datasets. Although the overall classification accuracy improved when we use both optical and SAR data, the classification accuracy might be even further improved if we adopt proper classification scheme (such as the layered classification).

Table 4. Classification accuracy of all datasets

	ETM+	SAR	4-band comb	PCA
Clear water	66.67	41.67	95.00	94.74
Turbid water	90.16	50.63	100.00	98.53
Tidal flat	82.35	0	82.35	82.35
Dry tidal flat	50.00	0	40.00	40.00
Halophytes	75.00	0	100.00	100.00
Bare soil	83.33	0	83.33	83.33
Urban	84.62	23.08	75.00	80.00
Forest	100.00	15.79	100.00	100.00
Paddy	71.88	44.19	91.30	91.67
Grass	54.55	0	50.00	50.00
Overall	78.00	40.00	86.50	86.50
Kappa	0.736	0.246	0.837	0.836

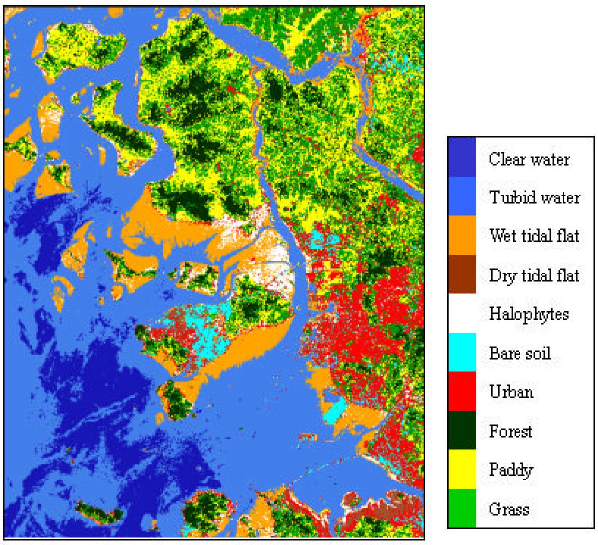

Figure 2. Land cover classification image of PCA fusion image using maximum likelihood classifier

5. Conclusions

This study attempted to test the synergic effects of using both optical and SAR dataset for the land cover classification in coastal region, which has relatively complex surface features that are difficult to separated by any single dataset. Although the visual interpretation on the combined datasets was not very familiar, we can better differentiate among the ten cover types. Such synergic effects were further verified from the spectral separability measure and the classification accuracy. In particular, those coastal area cover types were well classified in the fused datasets. At least for this particular study site of coastal region, the use of both optical and SAR data was effective for the cover type classification.

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