Korean Journal of Remote Sensing, Vol.22, No.5, 2006, pp.357~366

Spatial Pattern Analysis of High Resolution Satellite Imagery: Level Index Approach using Variogram

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Abstract : A traditional image analysis or classification method using satellite imagery is mostly based on the spectral information. However, the spatial information is more important according as the resolution is higher and spatial patterns are more complex. In this study, we attempted to compare and analyze the variogram properties of actual high resolution imageries mainly in the urban area. Through the several experiments, we have understood that the variogram is various according to a sensor type, spatial resolution, a location, a feature type, time, season and so on and shows the information related to a feature size. With simple modeling, we confirmed that the unique variogram types were shown unlike the classical variogram in case of small subsets. Based on the grasped variogram characteristics, we made a level index map for determining urban complexity or land-use classification. These results will become more and more important and be widely applied to the various fields of high-resolution imagery such as KOMPSAT-2 and KOMPSAT-3 which is scheduled to be launched

Key Words : high resolution satelite imagery, KOMPSAT, urban characterization, variogram.

1. Introduction

In the times of wide uses of commercialized high resolution satellite imageries, urban remote sensing is regarded as one of the important application fields. Currently, the main subjects and issues in urban remote sensing focus on the various attempts and approaches for these types of image data sets, distinguished from conventional image processing in remote sensing. The traditional image analysis or classification methods are mostly based on spectral information. However, the spatial information is more important according as resolution is higher and urban areas are more complex. Among several spatial processing techniques, variogram is a traditional method to process fundamentally for kriging, simulation and so on. The variogram has been used in geostatistics widely to presume the value of the needed location making use of the correlation of separated data in a specific distance.

Various trials were started to analyze not only field data but also digital image characteristics using variogram since the 1980's. However, unlike the field data, the variogram in remote sensing should be

Received 30 September 2006; Accepted 21 Octorber 2006.

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different from typical variogram in case of the form and analysis method. Curran (1998) and Woodcock *et al.* (1998a, b) provide readable introductions to the variogram in remote sensing. While Dungan (1998) reviews geostatistical techniques for estimation and simulation in a remote sensing context. Thereafter variographic analysis has been used for the segmentation and land-use classification (Benoît and Cavayas, 1997; Colombo *et al.* (2004); Wu *et al*, 2006). Some researches used for the assessment of rescale and evaluation of classification (Sergio *et al*, 2004; Li and Li, 2001). These studies used low or middle resolution imagery or aerial photo. The research using high resolution imagery or reflecting the variographic property in urban area is rare.

In this study, we tried to analyze high-resolution imagery in urban area using variogram. First of all, we grasped specific property in the variogram of image and how variogram is different according to sensor type, spatial resolution, location and window size. We also tried to analyze the spatial distribution of images using variogram and model some features, which appear in urban area commonly and investigate the unique characteristics of variogram in high resolution imagery.

2. Brief Overview: Variogram

The variogram is a two-point statistical function that describes the increasing differences or decreasing correlation, or continuity, between sample values as separation between them increases. Traditionally, the variograms has been used for modeling spatial variability rather than the covariance although kriging systems are more easily solved with covariance matrices. The typical variogram exhibits a rise that gradually slows to form a straight horizontal line (sill) due to the fact that increasing the distance between

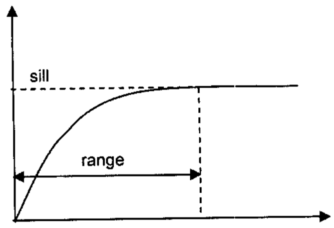


Fig. 1. A typical variogram.

their values. The height of the sill is normally proportional to the global image variance while the lag at which the sill is attained, called the "range," is generally a very good indicator of texture coarseness. The variogram can be calculated along transects usually (Atkinson and Danson, 1988; Curran, 1988; Ramstein and Raffy, 1989). But, it gives a better representation when calculated in more than one direction because texture is in many cases anisotropic (Davis, 1981; Cohen *et al.*, 1990; Woodcock *et al.*, 1998).

$$2r(h) = \frac{1}{m} \sum_{i=1}^{m} [z(x_i) - z(x_i + h)]^2 \qquad (1)$$

3. Results and Discussion

1) Variogram characteristics in image

The variogram of imagery has four wide differences from the variogram of earth science data. First of all, the number of data in remote sensing is more than field data usually because the number of pixel is same as the number of data. Secondly, the interval between data is fixed. As other earth science data have irregular distance ordinarily, some lag can't have the calculated value. However, there is a variogram value in every lag in case of imagery. The third property is that pixel value is not always similar to the around pixel values. Kriging is fundamentally assuming that each value is similar to the value of near position. For this assumption, non-existed value

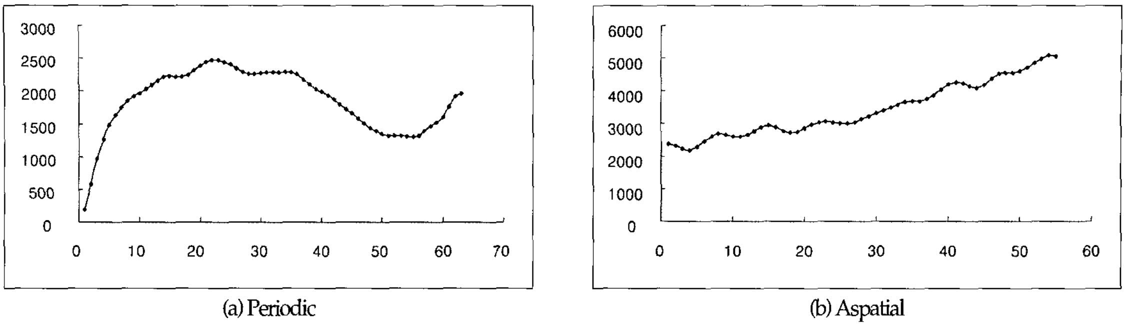


Fig. 2. Variogram types of actual digital images: Periodic and Aspatial.

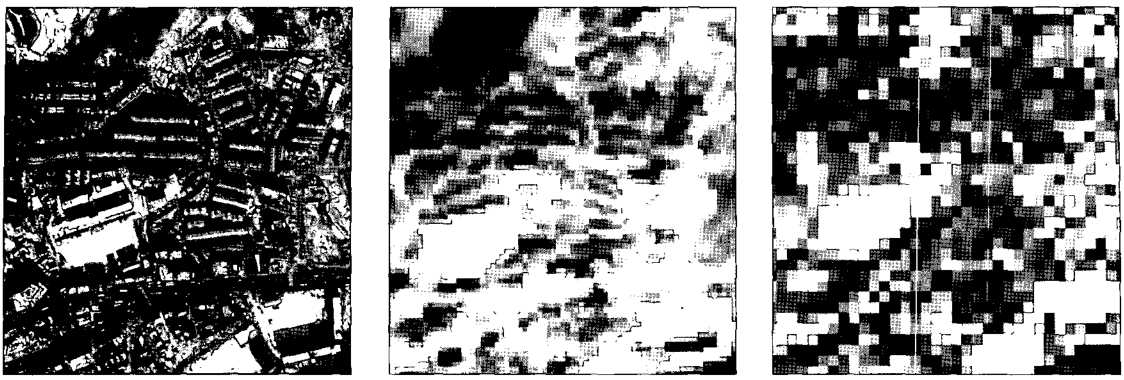
can be estimated. However, it may have a totally different pixel value in the boundaries in case of image. Last property of variogram in image is that the theoretical variogram does not fit to the experimental variogram. Spherical or Gaussian model used commonly can be available in some cases. However, variograms in urban landscapes are often of man-modified surfaces with a repetitive spatial pattern, and as a result this 'classic' variogram is relatively unusual. The two very common forms are the 'periodic' variogram (Fig. 2(a)) recorded across a repetitive pattern and the 'aspatial' variogram (Fig. 2(b)) recorded either along such a repetitive pattern, randomly on a homogeneous surface, or when using a support that is larger than the range.

2) The difference of variogram according to resolution

We can get totally different variogram according to resolution even though the images are obtained in same location. In case resolutions are different, the number of feature, feature size and kind of obtainable information are changed. Three types of different spatial resolution images were used at the experiments in this study: IKONOS 1 m, KOMPSAT 6.6 m and Landsat 15 m panchromatic imagery. IKONOS and KOMPSAT image are covered with regions around Namyangju-city bordered with Seoul, Gyeonggi-do, Korea. As shown in Fig. 3, every building can be divided correctly in IKONOS imagery. Meanwhile, KOMPSAT imagery has vague outlines and only large playground can be distinguished in Landsat imagery.

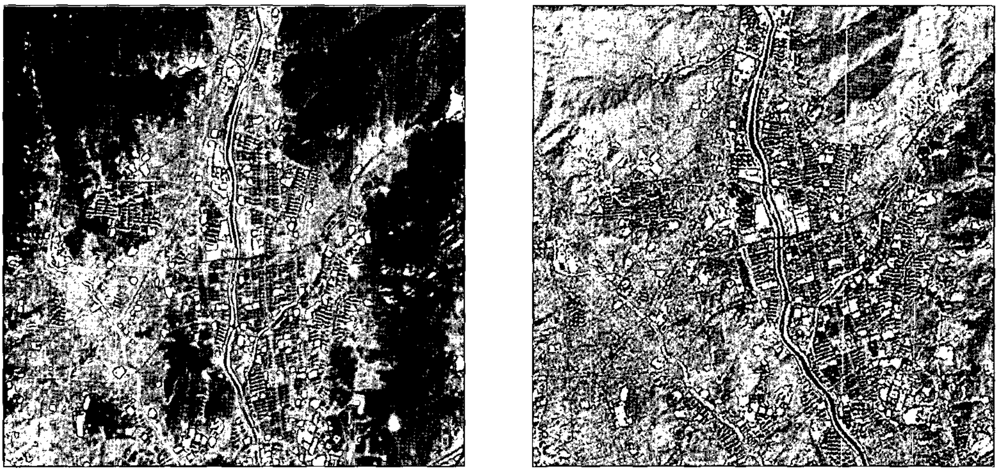
Fig. 5(a) shows the variograms of three images in Fig. 3. Unlike classical variogram, sill is not existed in KOMPSAT and Landsat imagery. Though the slant of variogram decrease, variogram increase according as lag is longer. In the early part, the variogram of IKONOS imagery increase dramatically. Afterward, slope decrease quickly, it has the smallest value in the closing part. Meanwhile, the variogram of LANDSAT imagery is larger than KOMPSAT imagery. These results show that the higher resolution is the higher variogram value is.

Fig. 4 shows KOMPSAT and LANDSAT imagery are covered with regions around Guri-city bordered with Seoul, Gyeonggi-do, Korea. These images have dense buildings in middle part and forest area on the border. The variogram of KOMPSAT imagery in this area has distinctive variogram shape. This has periodicity and looks like a sum of periodic function. If the periodicity of variogram analyze, we can get feature size, redundancy, some patterns. Fourier transform and wavelet transform can be used for periodicity analysis. Meanwhile, we can not identify building boundaries in LANDSAT imagery. Forest area is seldom noticed because they blend well with their surroundings. The variogram of LANDSAT imagery has totally different that of KOMPSAT Imagery.



IKONOS KOMPSAT LANDSAT

Fig. 3. Three sample images with different spatial resolution.



KOMPSAT LANDSAT

Fig. 4. KOMPSAT and LANDSAT images in the Guri-city.

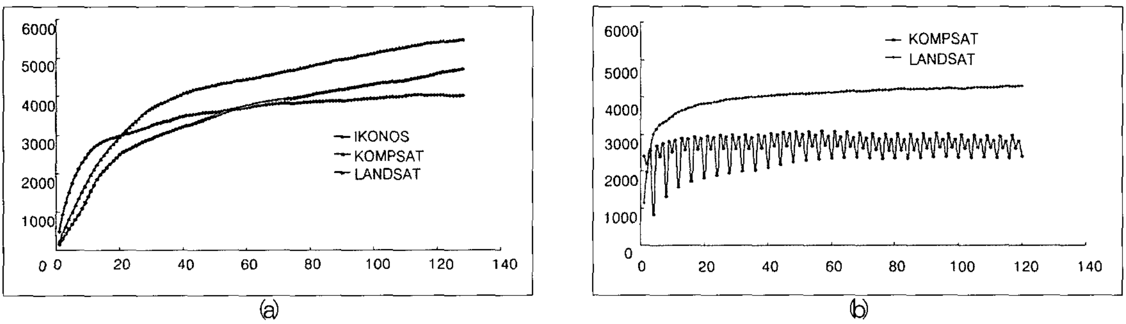
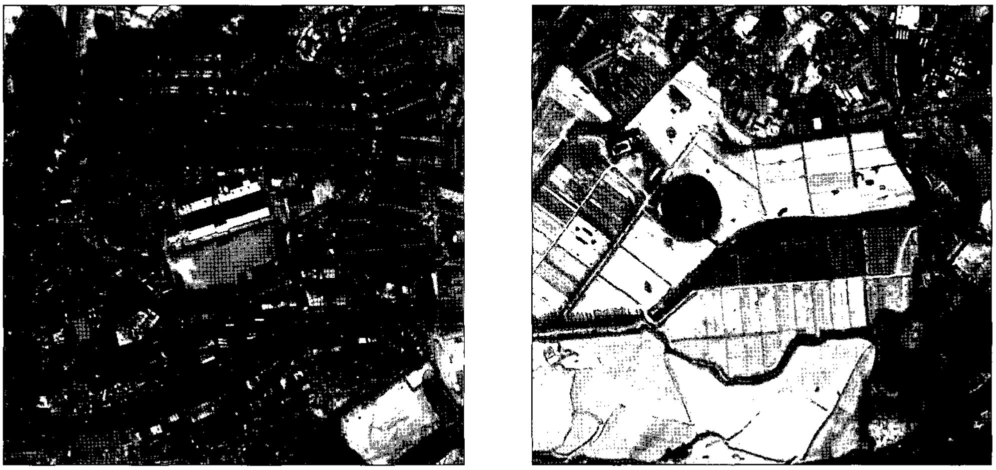


Fig. 5. The variogram results of two figures; (a) is the variograms of Fig. 3, (b) is the variograms of Fig. 4

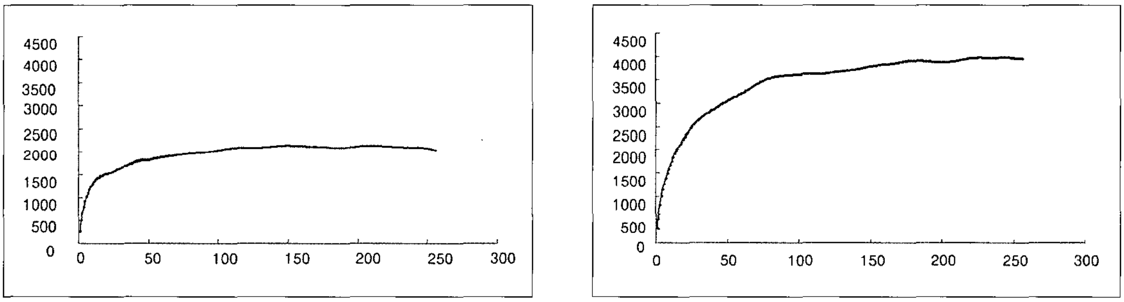
3) The comparison of variogram according complexity

Previous researchers have mostly applied to not urban area but rural area. Therefore variogram characteristics should be different from former results, in case of research intended for urban area. Fig. 6 shows two images with same resolution and different complexity. In Fig. 6 (a), urban area has



(a) (b)

Fig. 6. IKONOS images with different spatial pattern.



(a) (b)

Fig. 7. The variogram results of Fig. 6 (a) and (b).

complex and small features such as building and car. Meanwhile, rural area has large structure such as field and farm. So, the range value of Fig 7 (b) is larger than (a). Meanwhile, the nugget is higher in urban area. In case of sill, rural area has higher sill than urban area. It may be generated by contrast snow with the color of dark fields. Variogram might be influenced by not only complexity but also seasonal effect.

4) Pattern characterization using high resolution imagery

In urban area, many kinds of features are arranged complicatedly. Variograms of whole image mostly appeared in traditional variogram shape. However, specific variograms can be seen in the smaller sub images. First of all, we made 6 models, which can be seen in the urban area to confirm how variogram reveals. Fig. 8 shows the feature simple models being seen usually in urban area. Models encapsulated road, building, multi-building and so on. Each model has 64×64 in size.

Fig. 9 shows the results of variogram according to the models of Fig. 8. In case of the diagonal feature model, that variogram is a spatial variogram increasing continuously. The variogram of vertical feature model has a sill that gradually slows to form a straight horizontal line. When buildings are in the window, variogram shows repeated pattern and it is convergent to 0. The number of repeated pattern is same as that of buildings. However, real data should

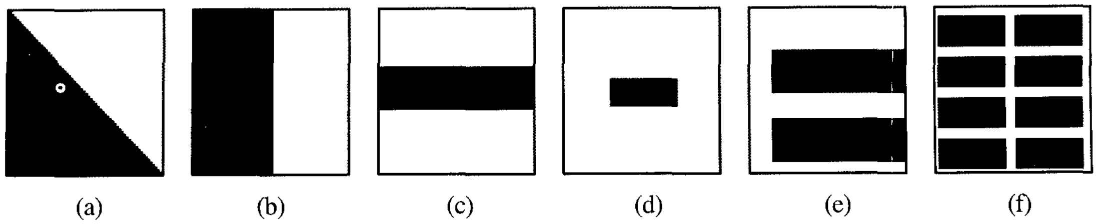


Fig. 8. Simple pattern types for variogram analysis.

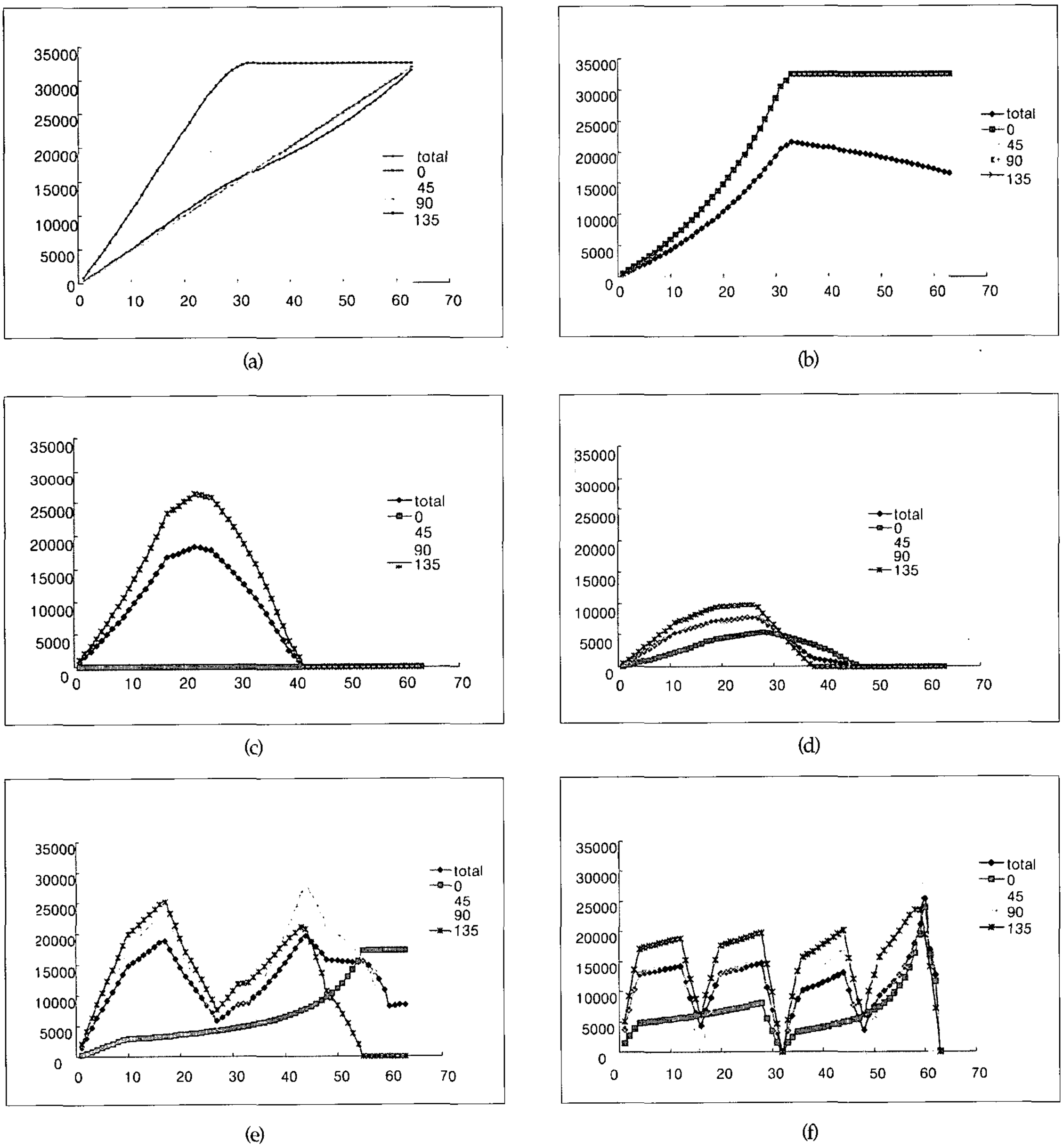


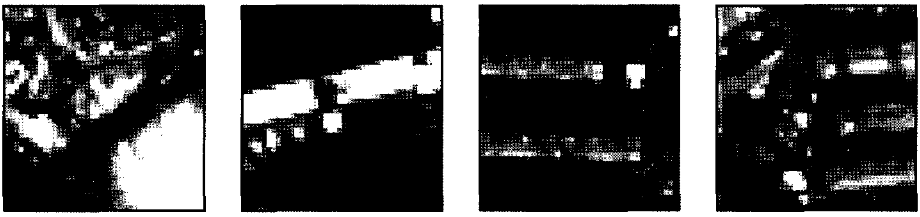
Fig. 9. The variogram results with respect to simple pattern types of Fig. 8.

be tested because these models simplify urban feature.

Fig. 10 shows the real images of 64 by 64. Four images are similar to the models selected for the test images. Fig. 11 is the variogram for Fig. 10. In case of real image, though it is a rather complicated, it is confirmed to be the similar trend as the model.

If we use the feature that the variogram has a tendency to decrease when one feature comes in the window, we are able to decompose the image according to the building size, because the window size including the whole building would be different according to the resolution or the size of the building. In this study, we have analyzed the image as steps and divided into the much smaller window, so if the convergence variogram shows up, the division would be stopped (Fig. 12).

Two types of different spatial resolution images have been taken into account in this study such as IKONOS 1 m and QuickBird 0.61 m imagery (Fig. 13). IKONOS image is covered with regions around



(a) (b) (c) (d)

Fig. 10. Cases of urban features shown in actual sub-image.

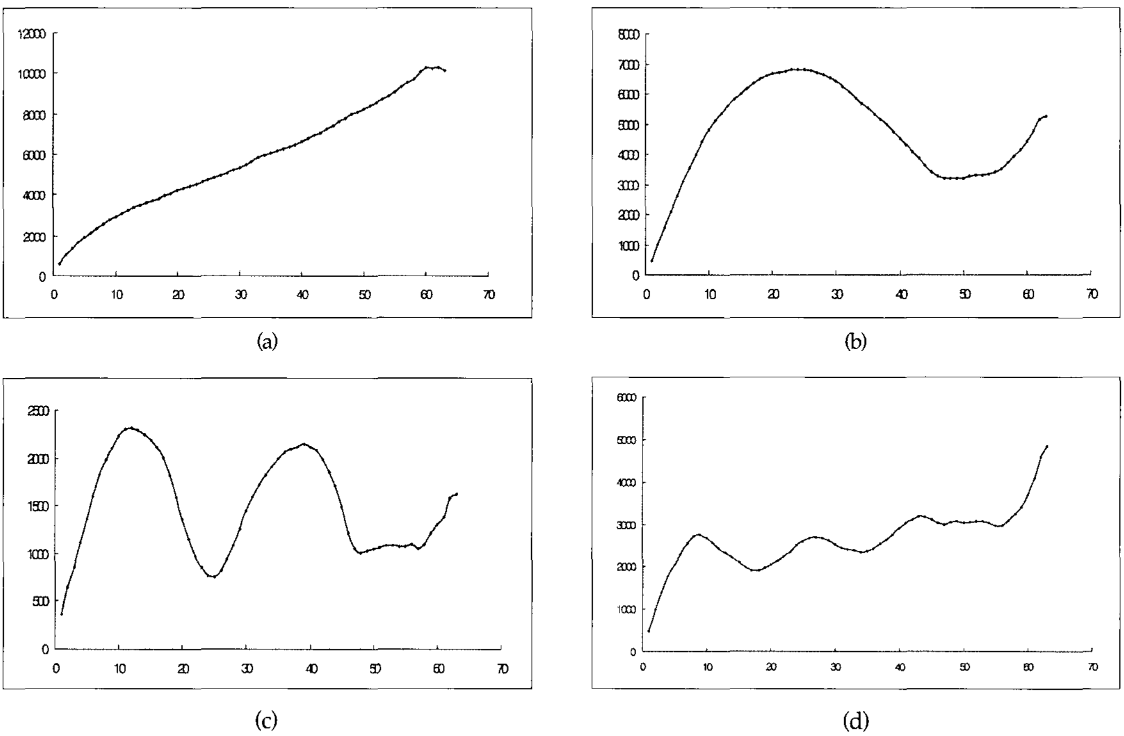
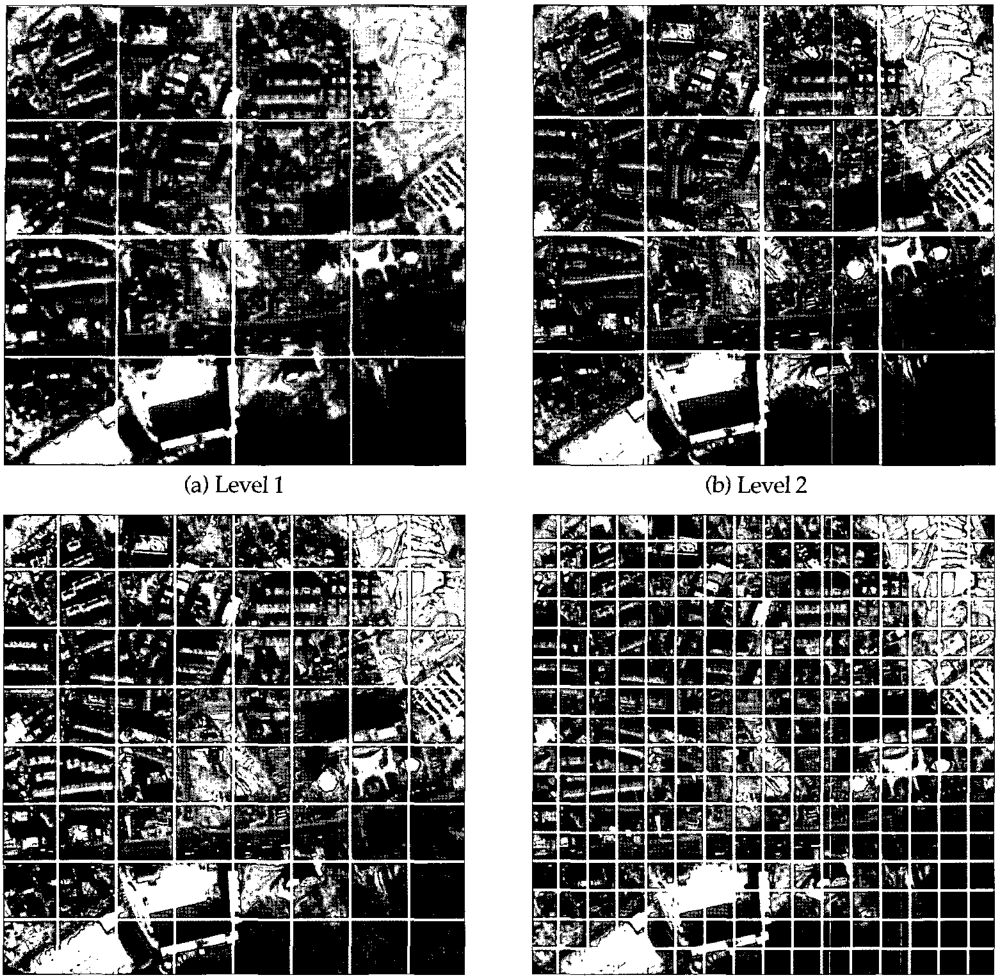


Fig. 11. The variogram results of Fig. 10.



(a) Level 1 (b) Level 2

(c) Level 3 (d) Level 4

Fig. 12. Level decomposition for spatial pattern analysis.

Namyangju-city and QuickBird image is covered with Yeouido, Seoul. On decomposing up to 32×32 window size (Fig. 13(a)), most features stayed inside window. While, most parts of the feature stayed inside of 128x128 windows in Fig. 13(b). This means Fig. 13(b) has bigger feature than (a). Level decomposition is illustrated in Fig. 12. The darker part means the bigger features. Not only feature size but also size of resolution has great influence on these results. Upon that imagery has same resolution, it will be used to index urbanization or building size. Upper-left part is more complex in IKONOS image. While lower-left side in QuickBird image is more complex as well. However, shadow effect and complex building shape make analysis harder in urban area. For the precise result, we should analyze the variogram with sliding window. Nevertheless, these index maps can be used for determining urban complexity or land-use classification because the index is influenced by feature size.

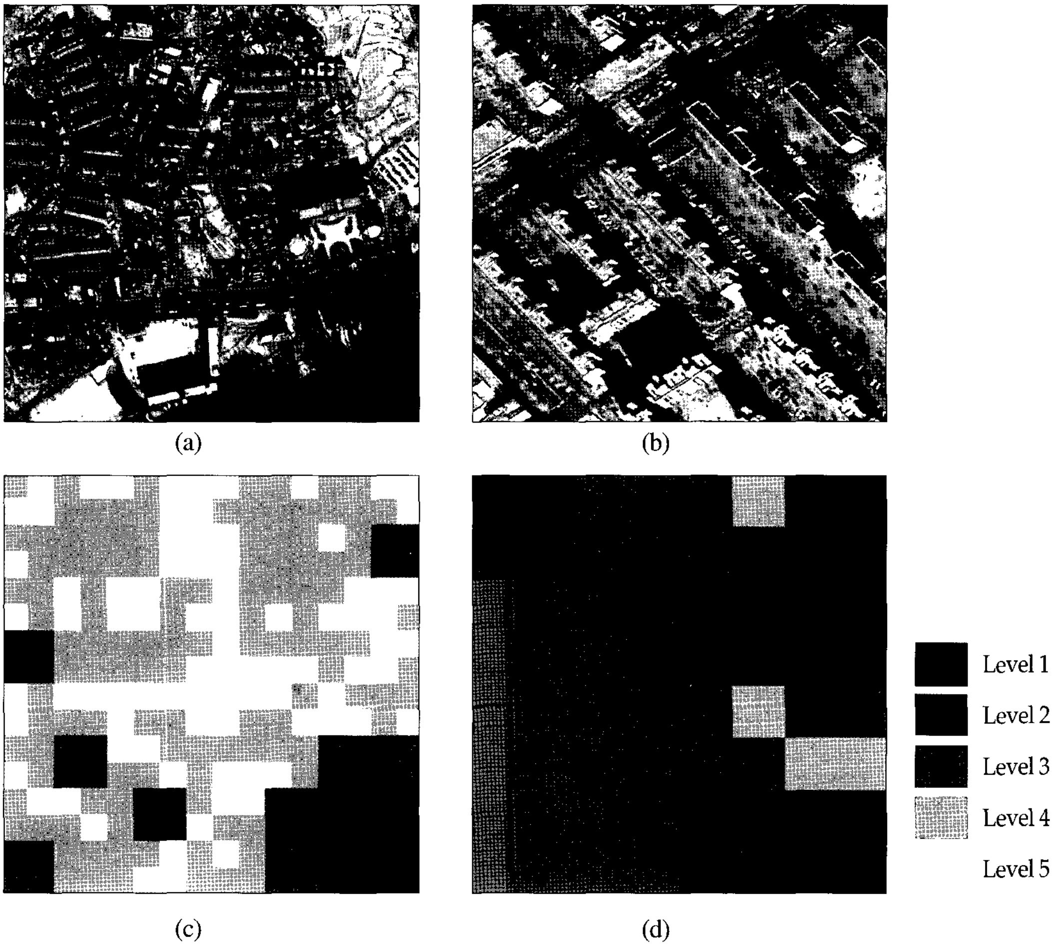


Fig. 13. Level index based on variogram analysis with respect to applied data sets.

4. Concluding remarks

In this study, we intended to compare and analyze what kinds of the specific property variogram of high resolution imagery in the urban area are shown. The variogram is various according to a sensor type, spatial resolution, a location, a feature type and so on. Variogram showed well the spatial characteristics of each images. Based on these results, we applied to high resolution imagery in the urban area. We tried to model the urban structures such as buildings and roads, which can be seen in high resolution imagery. After analyzing those variogram, we have corroborated the results using the real image tested. The outcome is that there is little difference between the variogram of the real image and that of model. Modeling results shows that urban features have the unique variogram. Besides using specific properties of the variogram in the image that the variogram decrease, if one feature comes in the window, we decomposed the image as steps and divided into a much smaller window and indexed the town image according to the building size. These results are expressed in the index map. This is helpful to detect the area where the specific size feature is distributed in or catch the general feature size with comparing decomposition level. It will also be used as a layer for the land-use classification or analysis of urban complexity to index urbanization or a building size. These results will become more important and be applied to various fields widely because KOMPSAT-2, which can take 1-m spatial resolution imagery, launched successfully and KOMPSAT-3 scheduled to be launched successively.

Acknowledgements

This work was a part of studies for KOMPSAT-3 Application Project, being supported by the Korea Aerospace Research Institute.

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