J-1.2.1 Study on decomposition methods for a remote sensing pixel for forest monitoring

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Abstract

Recently, improvement of forest survey and fusing between ground survey information and satellite information have been required, since it is correspondent to global environmental problem and also to forest management problem. In the multistage observation, the pixel decomposition method, which can estimate the component in the pixel of satellite data for the rough resolution, seems to be very much the importance. Then, the elucidation of characteristics of the pixel decomposition method is required. The analysis which adapted to the forest observation asks the requirements, such as 1) the situation in a pixel can be analogized, 2) the effect of the landform is small, 3) forest stand structure such as the evergreen/deciduous mixture rate of the upper layer tree can be distinguished, 4) the change of forest stand structure is proven even in the condition in which the vegetation is comparatively dense.

At first, the basic patterns were decided for applying the pattern decomposition method to forest area. Then, the pattern decomposition method was processed at each pixel, and the relevant analysis between the decomposition coefficient and forest survey data was carried out. As the result, the followings were proven; (1) By pattern decomposition it is possible to obtain information on the forest structure. (2) The conifer pattern decomposition coefficient (CPI) is proportional to the crown covering of the evergreen needle-leaved tree. (3) Broad-leaved tree pattern decomposition coefficient (VPI) reacts at the total amount of the vegetation. (4) The soil pattern decomposition coefficient (SPI) reacts to deciduous leaf quantity and soil. (5) The effect of the atmosphere to the VPI is less than that to the CPI. (6) The effect of the landform is reduced by the pattern decomposition coefficient. (7) In the Aomori cypress primeval forest zone, the effectiveness of pattern decomposition method could be confirmed. (8)The effectiveness of pattern decomposition method was confirmed even in the Kiso hinoki primeval forest zone. (9) Qualitative distribution information of coniferous trees with 30-meter resolution in the district forestry office unit was obtained for the first time.

Keywords; remote sensing, pattern decomposition, forest, mixel

1. Introduction

Forest stand information for forest management has mainly been obtained by the ground survey. The ecosystem of the forest changes by growth and transition for human utilization, and information renewal in every several years is indispensable. However, it is difficult to collect wide forest information periodically by the ground survey. Then, the utilization of satellite remote sensing data and aerial photograph is expected. The satellite sensor observes the wide range at one time. However, it is difficult that physical information such as stand volume is directly obtained from sensor data.

Recently, efficiency improvement of forest survey and fusing between ground survey information and satellite information have been required, since it is correspondent to global environmental problem and forest management problem. According to multistage observation data by the satellite, it becomes possible that wide and detailed forest covering information is obtained. In the multistage observation, pixel decomposition method which can estimate the component in the pixel of satellite data with the rough resolution seems to be very much the importance. Then, the elucidation of features of the pixel decomposition method is required.

The multistage observation became possible by the development of satellite positioning system (GPS) and geographic information system (GIS). By these technology, the systematization of information is attempted, and the collation between plot investigation data and satellite data in the forest becomes possible. As the result, features of satellite data can have also been well analyzed. It has been required that the ecosystem of the wide area is evaluated using this leading technology.

2. Research Objectives

In the forest survey of Japan, the matter as a difficulty of the satellite data utilization is described to the following. 1) Unit forest stands are small. 2) There are many mountain forests, and the effect of the landform greatly comes out at the observed value of the optics sensor. 3) The composition tree species is various, and the seasonal variation is big. 4) The forest plant including the lower layer vegetation is very minute. Therefore, "the analysis which adapted to the forest observation" with features such as 1) the situation in the 1 pixel can be analogized, 2) the effect of the landform is small, 3) forest stand structure such as the evergreen/deciduous mixture rate of the upper layer tree can be distinguished, 4) the change of forest stand structure is proven even in the condition in which the vegetation is comparatively dense, is required.

In the index of Landsat TM data used for the vegetation observation, there is normalization vegetation index (NDVI) using the data of visible band and near infrared band. However, this index is easy to receive the effect by the landform, and in the part with the dense vegetation, the value is saturated. Therefore, this index is not adequate for the forest observation of Japan. Then, the research method which can analogize the component in a pixel without receiving the effect of the landform, is required. This is very important even in the mutual association of multistage observation data of which the resolution differs. This is "the pixel decomposition method" as an object of this study.

2. The research method.

As a pixel decomposition method, there is the end member method (Tompkins et al.). This technique assumes the reflection spectrum of the pixel a total of reflection spectrum of cover material. Then, covering proportion in a pixel is estimated on the basis of the reflection spectrum pattern of the representative cover material. However, this technique receives the effect of the landform (slope azimuth and tilt angle), since it is dependent on the value of the reflection spectrum of cover material. There is the pattern decomposition method as one of the pixels decomposition methods which can reduce the effect of the landform (Fujiwara et al.). On the basis of basic spectrum pattern such as soil, vegetation, water, this technique regards the spectrum pattern of each pixel as a synthesis of those basic patterns. It seems to be able to reduce the effect of the landform, because the spectrum pattern in all channels is used without using the value of observed spectrum. However, the research for this technique was only conducted for the rice paddy area. Therefore, whether this pattern decomposition method could utilize for the forest survey was not clear. Then, the research was carried out for the purpose of the verification of the effectiveness in forest survey of pattern decomposition method in this study.

To begin with, the basic pattern was decided. Next, the pattern decomposition method was processed at each pixel, and the relevant analysis between the decomposition coefficient and forest survey data was carried out, and features of the pixel decomposition method were examined. In this study, the covering component in the woodland was made to be evergreen needle-leaved tree (cedar, Abies sachalinensis, etc.), deciduous broad-leaved tree (beech, Quercus mongolica, etc.), Sasa-bamboo, bare field. In pattern decomposition method of the TM data, all data except bands 6 is used. The pattern decomposition coefficient is calculated by the following method.

(1) The standardization of the spectrum pattern.

$A = (A1, A2, A3, A4, A5, A7)$.

wheree $Ai = (Di - Dimin) / Z$

$Z = \Sigma (Di - Dimin)$ $i = 1,2,3,4,5,7$ (band of TM).

It is necessary to decide minimum value Dimin with the close attention. The Z (the sum of the each band value) is handled here as an approximate quantity of the total of the light of a pixel. To divide the value of each band in Z is for correcting the difference between the incident light energy of the every pixel. As the result, it is considered that value (Ai) on the reflectivity is normalized.

(2) The basic spectrum pattern.

In the pattern decomposition method, soil, vegetation, water are used generally as a basic spectrum pattern (Fujiwara et al.). However, in the woodland, the water does not exist except in the mangrove forest. The vegetation which cover the surface in the woodland in Japan is conifers, broad-leaved trees, grass, Sasa-bamboo, etc.. The soil appears in cutover area and forest stands including the landslide scar. However, the following are considered as basic pattern: Evergreen needle-leaved trees, evergreen broad-leaved tree, deciduous tree, Sasa-bamboo, grass, soil, etc.. It seems to be able to analyze the covering situation of the forest by applying pattern decomposition method by defining and appropriate basic pattern considering target area and season. Then, pixels such as soil, broad-leaved tree, conifer were chosen from the TM data, and it was made to be the basic spectrum pattern (S V C, etc.).

(3) The pattern decomposition coefficient.

It is assumed that the spectrum pattern of each pixel is the linear addition of three basic spectrum pattern.

$A = SPI * S + VPI * V + CPI * C + e$:

Where e is immoderate term.

SPI,VPI,CPI is calculated in order to minimize e.

SPI,VPI,CPI is called pattern decomposition coefficient for the each base spectrum pattern.

3. Study Area

As the study areas for this research, next 4 places were chosen. (1) Hokkaido Tomakomai Forest Service service area, (2) Yaku cedar forest land band, (3) Shimokita Peninsula cypress primeval forest zone, (4) Kiso hinoki primeval forest zone.

The forest in the Hokkaido Tomakomai Forest Service is easy to evaluate the forest data, since big plantation forests are found. Moreover, the remote sensing data is obtained in the ideal situation because there are small effects of the landform. Using the data of this region, fundamental features of pattern decomposition method were studied. Conifer plantations such as Yezo Spruce and Abies sachalinensis are main for the forest in this region, and there is the Sasa-bamboo as lower layer vegetation.

The effect of the landform in pattern decomposition method can be examined, since it is a very steep landform, Yakushima Island.

Shimokita Peninsula is the region where the cypress primeval forest is dominant, and it is called one of the three great beauty forest (cypress of Shimokita, cedar of Akita, hinoki of Kiso) in Japan. Since the data of complete enumeration of plotting size 40mx50m was obtained, in this region, the comparison between TM data and forest survey data was possible.

The Kiso hinoki forest is also one of the three great beauty forest, as it was mentioned earlier. On the basis of the result got in other region, the stand volume estimation of hinoki by pattern decomposition method was verified. By this, it was considered that features of pattern decomposition method in the conifer stand volume estimation and the usability were clarified.

4. Results and Discussion

(1) Fundamental features of pattern decomposition method (plantation in Hokkaido Tomakomai Forest Service and Shimokita).

TM image in the fine day was chosen. Images of the Tomakomai region are as follows: 1986/6/26,1987/5/21,5/28,/6/22,1988/5/30,1990/4/11,4/27,5/29,6/5,6/14,8/8,10/11. The analysis for the conifer plantation was carried out even in the image of Shimokita Peninsula and Tsugaru Peninsula. Acquisition dates of the satellite are as follows. Shimokita Peninsula : 1996/6/14 Tsugaru Peninsula : 1991/5/7

The forest age was used as a ground survey data. Though the forest age is not exactly physical quantity of forest stands, the correlation is high between forest age and tree height, basal area. As a result of comparing pattern decomposition coefficient of the satellite image with the ground survey data, it was able to be confirmed that the value of conifer pattern decomposition coefficient (CPI) increased in the part with many conifers. In addition, following fact clarified as a result of comparing the CPI of the plantation with the forest age.

1) In the forest over 10 years, CPI and forest age show the positive correlation. The CPI shows the maximum value in the forest for the 35-40 year, and it is the value which is almost same afterwards. The CPI tends to lower, when the forest age rises further.
2) The positive correlation in CPI and forest age over forest age 10 years can be always confirmed regardless of season, region.
3) There is the effect of cloud and thin cloud. This reason is for destroying the spectrum pattern, since the effect of thin cloud is different in the wavelength.

These features of the CPI are similarly observed even in not only forest in the flatland in

Tomakomai but also Shimokita Tsugaru. This fact shows that the monitoring of the conifer by the CPI is possible even in the mountain, because pattern decomposition method can reduce the effect of the landform.

In the data of Tomakomai, the relationship between the forest age in the conifer plantation was examined for the VPI value. As the result, in the data in spring and autumn, there is the positive correlation during VPI value and forest age in the evergreen needle-leaved tree forest by forest ages of 20. However, in the data from the early summer to the summer, VPI is saturated in forest age 10 years, and in the higher forest age, the correlation between VPI and forest age is very small.

And, VPI tends to increase over the summer from the spring, and the forest age shows the tendency in the monotonous increase even in the forest for the 1 - 5 year. And, the data in which the year differed was compared.

It is proven that the VPI value reflects the total amount of vegetation covering of each pixel. And, it is proven that VPI is also reacting to the seasonal variation of the considerably dense forest (Fig.1), because the value rises even in the plantation where the forest age is high from the spring over the summer.

(2) The evaluation of the landform effect (case in Yakushima Island).

Considerable area of the virgin forest has been registered Yakushima Island as world natural heritage. On the rich vegetation of Yakushima Island such as the Yaku cedar, much information is accumulated. However, it has been got in the ground. Therefore, the renewal takes time, and there is some information which does not coincide with present state. Especially, the change by cuttings of the Yaku cedar, etc. is not reflected for the vegetation map.

Yakushima Island is the island which is very much rich in the change of the landform of the difference 1935m an altitude . Therefore, the effect of the landform is made to be one of the large problems, when the vegetation situation is analyzed using satellite data. Satellite data are observation energy value of the optics sensor, and the effect of the landform is not avoided. There is the most general-purposive vegetation index NDV, and this greatly receives the effect of the landform. In this study, the effect of the landform in pattern decomposition method was analyzed.

The pattern decomposition method was applied to the TM data and estimates the Yaku cedar distributional area. By this study, new Yakushima Island cedar distribution map was made. TM data are used and it was proven that the broad-leaved tree could be distinguished from the conifer in making 0.85 of the VPI value to be a threshold in the image in May, when the result of pattern decomposition was compared with vegetation map (Miyawaki). In comparison with this result and existing vegetation map, the change in the primeval forest area was examined (Fig.2).

(3) The application to natural cypress stand volume distribution and available stand volume estimation.

In this region, it may be assumed that the conifer in the primeval forest is a cypress. Then, the cypress was estimated by relating satellite data to the physical quantity (stand volume) of the conifer.

The TM image used is the data on June 14th, 1996 of TM. Though the main evergreen needle-leaved tree in primeval forest is a cypress, the plantation is a cedar. To begin with, distribution map of the primeval forest was made by digitizing forest planning map of contraction scale 1/20000. And, district forestry office boundary vector data (Fig.3) and forest function division vector data were also made from forest planning map.

41 plot data were got in study area in 1996 : The fundamental size is 40m~50m(0.2ha). The survey position is being described by the investigation person on the forest base map with

the scale of 1/5000. The result of examining the single correlation between pattern decomposition coefficient and ground survey data is described on the table 1. It was CPI value and basal area per ha that the correlation was the highest. Then, the correlation equation between CPI value and basal area per ha was calculated.

As the result, the estimated formula consisted as following.

G(basal area/ha) =2.927CPI-8.770.

The constant term part is CPI value of the broad-leaved forest.

Using this equation, the basal area of each pixel was estimated. This time, the upper limit of basal area per ha was changed to 75 m2 according to the plot data. And, next equation was obtained, when the relational expression between basal area G per ha and average stand volume V was obtained. V=5.263G**1.127.

The distribution image of stand volume of the natural cypress was made from this equation(Fig.4). And, all stand volume was calculated to every district forestry office, and it was compared with stand volume of the forest survey notebook. In the comparison of the district forestry office unit, cypress estimation stand volume by the satellite was 2.72 times from 1.47 times of the forest survey notebook data (average 1.77 times).

The distribution of stand volume per ha of each district forestry office consisted like Figure 5. The state of the distribution of the cypress forest, which is not proven only at the numerical value of stand volume, is proven from this figure. For example, in case of Kawauchi district forestry office, average stand volume is low in most forest, and there seems to be seldom the good forest of the natural cypress. In case of Ohata district forestry office, there is stand volume of many cypresses, and it is proven that the good forest is also abounding. In three district forestry offices (Mutsu, Wakinosawa, Yokohama) with the almost equal average stand volume value, cypress stand volume distribution map was compared. It is proven that forest stands in which average stand volume is low are frequent for Mutsu district forestry office. Like this, information on the quality of resources is obtained in the pixel decomposition method so that stand volume per ha may can estimate it at the every pixel. This is to deserve the attention. Until now, the scatter diagram on such resources was not obtained, because that one classification category corresponded for the every pixel was general. This is the knowledge which is very useful in the forest management, and it seems to be a largest advantage of the pixel decomposition method.

In addition, it was tried that information of the available quantity of the cypress was obtained in combining stand volume distribution map with GIS. The relationship between distance from the forest road and average stand volume of the cypress and primeval forest rate is shown in Figure 7. Primeval forest rate and stand volume per ha increases, as the distance from the forest road consists of the way within 200m in the distance. In the forest away from the road over 200m, the primeval forest rate increases, and average stand volume decreases. This seems to be because the way was run through the forest with much stand volume of the cypress. The rate of the primeval forest is over 50% even within 50m of the distance from the forest road in Ohata. In Kawauchi, it is 50% or less on the rate of primeval forest within 200m from the forest road. From this fact, it is proven that cutting around the forest road in Kawauchi considerably advances in comparison with Ohata. The relationship between slope angle and average stand volume and between slope angle and rate of the primeval forest are shown in Figure 6. With the increase of slope angle, the following increases : Primeval forest rate and stand volume per ha. From these figures, forest cutting in Kawauchi seems to considerably progress in comparison with Ohata. In Ohata, stand volume of the available cypress in which the distance from the forest road is in the place of 100m and 25 or less degree of slope angle is 14.9% of all stand volume. In Kawauchi, this is 14.3%. Cypress stand volume in the production forest in these conditions is 8.6%in Kawauchi and 9.7% in Ohata. In Ohata, it is 19.9% on stand volume in the production forest, when the condition of the distance from the forest road was made to be 200m, and in Kawauchi, it is 16.2%. At present available cypress stand volume seems to be 20% or less of all stand volume. By this study, the distribution of the cypress would be able to be grasped by relating ground information to the index of satellite data. And, it was possible to estimate available cypress stand volume by combining distribution map with GIS information.

(4) Natural hinoki stand volume and available quantity estimation.
In Kiso, recent forest survey data was not obtained. Then, the aerial photography interpretation material of the primeval forest made from 1966 during 1974 was used. Since the investigation region (0.1ha, 31.6m four quarters) is being described on the aerial photography, in this material, the identification of the place is possible. For the each investigation point, the following have been obtained : Averages tree height, average diameters, number of trees, stand volume, tree species and the proportion, locations, etc.. 58 ground survey sites in Otaki district forestry office were confirmed by satellite data, recent aerial photography, field study, and the point without large change was utilized for the analysis. The finally used aerial photography interpretation material was 22.

The TM was taken on June 18th, 1998. The data of this season seems to be suitable in the separation between broad-leaved tree and conifer. Many primeval forest of Kiso have formed pure forest of hinoki. Therefore, the conifer is almost 100% forest on forest stands of the ground survey. It is necessary to gain the distinction for the minute difference of such dense forest, when stand volume of hinoki of Kiso is estimated. Then, it was considered that the combination of basic pattern which specialized for the analysis of the Kiso primeval forest was made. As a representative cover material, the result of ground survey showed that there was "conifer, broad-leaved tree and Japanese larch, Sasa-bamboo, cutover area". And, it was possible to specify elderly and dense forest very much in the protected forest. Then, the spectral reflection pattern was also added, and four sets were made by the preparation of five basic patterns on the basis of it. The combination of the basic pattern is next four : [conifer, broad-leaved tree, Sasa-bamboo] , [dense conifer and broad-leaved tree, Sasa-bamboo], [conifer, broad-leaved tree, soil], [dense conifer and broad-leaved tree, soil] Pattern decomposition was done using this combination. The correlation between the result and ground survey data is shown at table of 1. Next fact is proven from this table.

The equation which estimated the basal area per ha of the conifer from the CPI was deduced. As the result, the estimated formula consisted as following.

$G=63.9 * CPI \quad (r=0.71)$.

And, the relation between basal area per ha and stand volume consisted as following.

$V=8.065 * G \quad (r=0.82)$.

From these equations, stand volume (/ha) of the every pixel was calculated, and the estimation pixel was made. 1350m3 stand volume was set from the ground survey data as an upper limit. In the relation between stand volume and average basal area of the complete enumeration point, the local difference could not be recognized. The following was obtained : Stand volume per ha and stand volume of the conifer of each subcompartment. And, it was compared with all stand volume on the forest survey notebook in every subcompartment. The result consisted like the following. The relationship between forest survey notebook and conifer stand volume estimate. Estimate =0.858 * [forest survey notebook value] (r=0.897).

5. Conclusion

As pixel decomposition method which enabled forest monitoring of the every pixel according to satellite data, the features were analyzed from the viewpoint of pattern decomposition method in various forests. As the result, the fact like the following was proven.

1) By pattern decomposition which is the pixel decomposition method, it is that the pixel in the woodland generally develops in conifer pattern, broad-leaved tree pattern and soil pattern, and it is possible to obtain information on the forest structure.
2) The conifer pattern decomposition coefficient CPI is proportional degree of the crown covering of the evergreen needle-leaved tree.
3) Broad-leaved tree pattern decomposition coefficient VPI reacts at the total amount of the vegetation.
4) The soil pattern decomposition coefficient SPI reacts to deciduous leaf quantity and soil.
5) The effect of the atmosphere of the VPI value is less than that of the CPI value. And, it is sharp for the seasonal variation of the dense evergreen needle-leaved tree forest.
6) The effect of the landform is reduced the pattern decomposition coefficient.
7) In the Aomori cypress primeval forest zone, the effectiveness of pattern decomposition method was able to be confirmed.
8) The effectiveness of pattern decomposition method was able to confirm even in the Kiso hinoki primeval forest zone.
9) Qualitative conifer distribution information of the district forestry office unit was obtained for the first time in this study.

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