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Analysis of Detailed Geographical Features using Shadow of Satellite Images in the Case of Illegal dumping site on the Border between Aomori and Iwate Prefectures

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Recently, the analysis of geographical features by digital elevation models (DEM) which are made from satellite images, has become a widely researched topic. However, espacially in the case of old satellite image, DEM or the stereo pair to make it might be hard-to-find. Then we developed the estimation method for three-dimensional detailed geographical features shape using shadow of satellite images. In this study, we investigated the influence on the result of estimation by choosing the boundary of a shadow. Also, we examined the threshold of the brightness to discern the shadows of geographical features from old satellite images.

Key Words : Geographical feature, Satellite image, SPOT, ASTER, Illegal dumping site

1 INTRODUCTION

Recently, high resolution satellites such as SPOT (panchromatic resolution : 2.5 m) and QuickBird (panchromatic resolution : 0.6 m) have begun to be operated, and we are now able to obtain high resolution satellite images. Thereby, the analysis of geographical features using digital elevation models (DEM) made from satellite images has become a widely researched topic[1].

We take notice of an illegal industrial waste dump site on the border between Aomori Prefecture and Iwate Prefecture[2][3][4]. This site is one of the biggest dump sites in Japan. The area of this site is about 27 ha and the amount of waste is estimated to be more than 1,000,000 t. The waste includes sludge, compost, incomplete RDF (Refuse Derived Fuel) and incineration ash. Moreover, small amounts of organic chlorine compounds and medical waste have been found.

There is a river next to this site, and the river is the source of water supply of Takko town in the vicinity. Therefore, serious influences such as rumor damage to the farm products of Takko town and safety of life of the local residents are involved in this problem. And immediate measures to detect and prevent environmental pollution are required.

The area of the illegal dump site at issue is about 500 m square. Inside the white circle on Figure 1, it is said that there was a mountain stream before. However we cannot see it now. We suspect that this is because most of it has been filled with a large amount of waste.

It is very effective in the expansion expectation of pollution and the renunciation amount of waste according to changing in

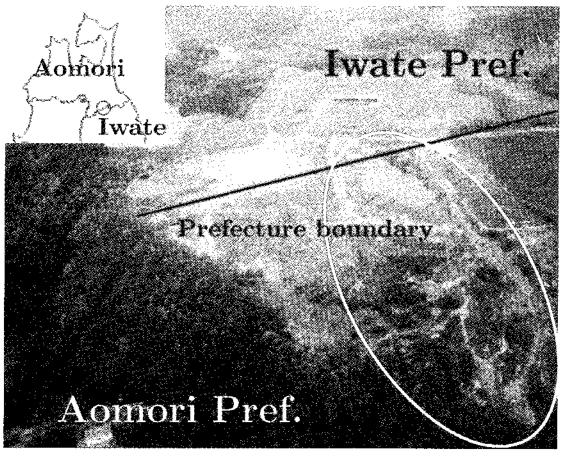

Figure 1 Aerophotograph of illegal dumping site

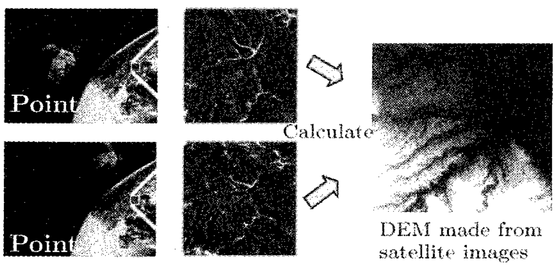

Figure 2 How to make DEM from stereo pair satellite images

geographical features during present in the past in this place.

Usually, a DEM is made from a stereo pair of satellite images. A stereo pair is obtained by taking a picture of the same place at a different angle at almost the same time, like in Figure 2. A DEM is obtained by calculating the altitudes of the features from the gaps in relative positions of the same features in these images. However, in the case of old satellite images, most of them have no stereo pair. Therefore, we cannot make a DEM from old images. Hence, we have to calculate altitudes using the images. One of the calculation methods is photogrammetry. In this method, an altitude is calculated from the gap of a relative position of the same surface of the earth object between stereo pair images which are taken on the same place from another angle. Hence it is impossible to calculate without stereo pair in this method. And almost of old satellite images do not have even stereo pair. Therefore we need other way to calculate altitude of old images.

2 METHOD OF CALCULATION

2.1 Calculation of Relative Altitude using Shadow (CRAS)

In the case of old satellite images without a stereo pair, we should obtain information on the altitude from a single image by any means.

Most high resolution satellites take images of land surfaces as optical images in the visible spectrum. One of the kinds of information on altitude in two-dimensional satellite images without DEM is the self shadows made by sun light. A shadow appears when an angle of inclination of a surface is larger than the elevation angle of the sun light.

Now, location of the sun is shown using θ_v and θ_h as shown in Figure 3. And the start point of a shadow is shown as σ^s and the end point is σ^e. σ^s and σ^e is located on the lattice in different direction from the sub light. If the length between σ^s and σ^e is shown as l, the difference of elevation h can be calculated using following equations:

$$h = l\cos\theta_{h'}\tan\theta_v, \tag{2.1.1}$$

$$\theta_{h'} = \theta_l - \theta_h. \tag{2.1.2}$$

To use this method, it is necessary to recognize which part is shadow in the satellite image. For that purpose, a target place and its surroundings should first be divided according to color information. In addition, the place where brightness changes suddenly for a similar color area should be detected.

2.2 Estimation of Altitude Inside of Shadow (EAIS)

In the aforementioned method, the inside state of a shadow cannot be known although relative altitudes at start and end points can be calculated. Therefore, we developed a method to estimate the internal state based on the angle of inclination in the vicinity of both ends of the shadow.

In Figure 4, L_s is the start of a shadow and L_e is the end. The estimation method is applied to area between L_s and L_e. $\boldsymbol{\sigma}_{i,j}$ is condition variable of each lattice point defined as a normal vector.

When the height of the position (i, j) is shown as $h_{i,j}$ and distance of pixels is shown as Δr, normalized normal vector as follows:

$$\boldsymbol{\sigma}_{i,j} = \frac{(-(h_{i,j}-h_{i+1,j}), -(h_{i,j}-h_{i,j+1}), \Delta r)'}{\sqrt{2h_{i,j}^2 - 2h_{i,j}(h_{i+1,j}+h_{i,j+1}) + (h_{i+1,j}^2 + h_{i,j+1}^2) + \Delta r^2}} \tag{2.2.1}$$

Seen locally, it is thought that the normal vector of one point tends to be same as that of a neighboring point because of continuousness in geographical features.

When already-known altitude points are assumed to be external altitude field and indeterminate points are assumed to be altitude conditional variables, this system is shown using the following Hamiltonian equation:

$$\mathcal{H} = \sum_{i,j}[-J \cdot S_{i,j}(\boldsymbol{\sigma}_{i,j} \cdot \boldsymbol{\sigma}_{i+1,j} + \boldsymbol{\sigma}_{i,j} \cdot \boldsymbol{\sigma}_{i+1,j}), \\ -K_{i,j}\boldsymbol{s}_{i,j}\boldsymbol{\sigma}_{i,j}] \tag{2.2.2}$$

In this equation, $J_{i,j}$ is a tendency factor that the condition of one point is similar to its nearest neighbor point. When the nearest neighbor is on the start of a shadow, if the inclination angle condition of the next point is lower than zero, $J_{i,j}$ is zero. Because when the inclination angle of the start of a shadow is lower than zero, it is thought that the inclination has changed as rapidly as at a cliff. Otherwise $J_{i,j}$ is the constant number J. $\boldsymbol{s}$ is an alreadyknown altitude value. If $\boldsymbol{s}_{i,j}$ exists on the position (i, j), $K_{i,j}$ is the constant number K. Otherwise $K_{i,j}$ is zero.

In a case in which a final solution cannot be known like this problem, the Bayesian Learning Algorithm is a powerful method to solve such problems[5]. In this method, unknown parameters are treated as distributions of probability. Prior distributions are given by our transcendental knowledge for the system. This is the aforementioned information that the condition of one point is similar to its neighborhood. Such information is contained in equation (2.2.2). Using this information, we can get the equilibrium state of the system using Maximum A Posteriori Estimation.

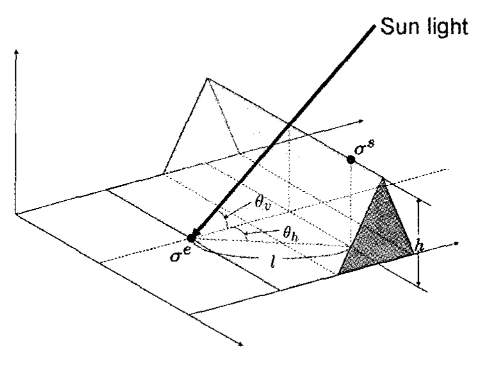

Figure 3 Difference of elevation between start and end point of shadow

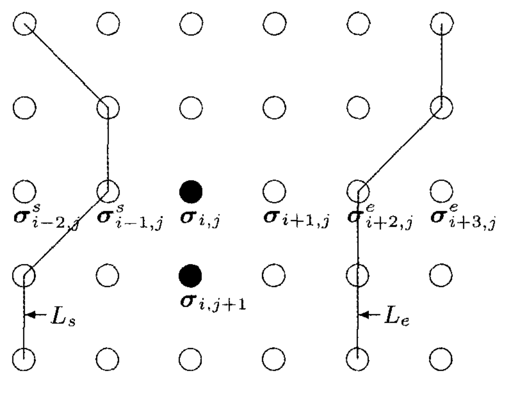

Figure 4 Points inside of shadow

In the initial state, condition variable $\sigma_{i,j}$ is set to the elevation angle between the start and end of the shadow. This nonequilibrium distribution is named y. And the equilibrium distribution when the parameter takes the optimal value is named x. When J and K are assumed to be unknown parameters, their most suitable values are shown in the following:

$$(\hat{J}, \hat{K}) = \arg\max_{J,K} Pr(X=z \mid Y=y, J, K). \qquad (2.2.3)$$

When $\hat{J}$ and $\hat{K}$ are selected as suitable parameters, the distribution of probability gives the most specious equilibrium state $\hat{x}$ as the following:

$$\hat{x} = \arg\max_{z} Pr(X=z \mid Y=y, \hat{J}, \hat{K}). \qquad (2.2.4)$$

Moreover, equation (2.2.4) is rewritten using Bayes' formula and equation (2.2.2) as follows:

$$Pr(X=z \mid Y=y, J, K)$$

$$= \frac{Pr(Y=y \mid X=z, J, K) Pr(X=z \mid J, K)}{\sum_{z'} Pr(Y=y \mid X=z', J, K) Pr(X=z' \mid J, K)}$$

$$= \frac{\exp\left(-\sum_{i,j} \sigma_{i,j} \cdot [J_{i,j}(\sigma_{i+1,j} + \sigma_{i,j+}) + K_{i,j} s_{i,j}]\right)}{\sum_{z} \exp\left(-\sum_{i,j} \sigma_{i,j} \cdot [J_{i,j}(\sigma_{i+1,j} + \sigma_{i,j+}) + K_{i,j} s_{i,j}]\right)} \qquad (2.2.5)$$

Now, optimal parameter J and K are obtained by these expressions. Thus, one of the most specious distributions x is generated using Monte-Carlo simulation. And we will be able to calculate altitude from the inclination angle conditions that are obtained.

3 EXPERIMENTAL DATA

In this study, we used following satellite data.

Table 1 Information of Satellite Data

	1988	2004
Satellite	SPOT-1	ASTER
Mode	Panchromatic	Multi(VNIR)
Resolution	10 m	15 m
Date(UTC)	1988-11-09 01:33:22	2004-09-16 01:30:54
Geometric Collection	Ortho	Ortho

4 RESULTS AND DISCUSSION

4.1 Verification using existing DEM

We verified the effectiveness of the method using a DEM in which the resolution was made to be low. It was verified by comparing the altitude data by this method with the DEM of former resolution. In this verification, the ASTER altitude data and the ASTER VNIR data were used.

First, we show the result of verification of the CRAS method in Table 2.

Table 2 Result of comparison CRAS and DEM

Avarage of difference	0.986 m
Maximum difference	4.450 m

In this table, the difference is altitude difference between the start and the end point of a shadow. As a result, there is comparatively enough accuracy, and it can be said that the CRAS method is effective.

Next, the result of estimation inside of shadows using EAIS is shown. The maximum error between the original DEM and estimated result is 5.2 m. It is thought that this is comparatively good accuracy considering that the vertical direction error margin of original ASTER altitude data is within 20 m.

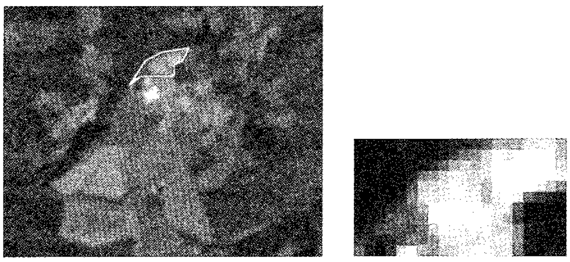

Figure 5 Example of applied area of ASTER VNIR data

4.2 Applying to old satellite image

We tried to apply the method we had developed to the SPOT image of the illegal dump site of 1988. In Figure 6, it is possible to see a mountain stream in the white circle. The south side of the mountain stream is pasture. On each edge of the mountain stream, the altitude assumed little change. Then it was made into a boundary, and the altitude in the enclosed area was estimated.

In Figure 7, the white line shows the present altitude. The difference of the depth of the mountain stream between the present altitude and this estimation is about 15 m.

Figure 6 SPOT1 image of 1988

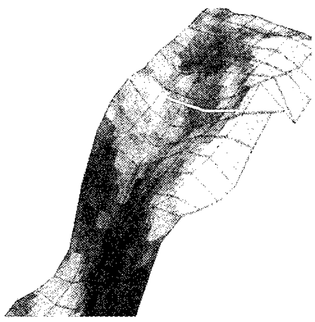

Figure 7 Result of applying to old image

Table 3 Influence of boundary to estimation result

Threshold of relative brightness	0.4	0.5	0.6
Depth of bottom in mountain stream	12 m	15 m	17 m

4.3 Influence by boundary of shadow

According to the boring investigation of Aomori Prefecture, the depth of the mountain stream in Figure 6 is about 21 m. However, the depth that had been shown by our calculation was only 15 m. It is thought that one of the influences for this was the method by which the boundary was chosen. The boundary of the shadow had been selected by human eyes arbitrarily. However, it is necessary to examine the standard for the decision numerically to automate the calculation and apply it to a wider area. And the relation between the boundary of the shadow and the calculated shape should be examined, too. The threshold is defined by relative brightness with the neighboring pixel. The result is shown in Table 3.

The difference is thought to be an influence by the shape of the selected shadow and the angle of its boundary. The appropriate threshold is influenced by geographical features. Therefore, it is necessary to build the peculiarity of the targeted geographical features into the model, and it is thought that this would allow automatic and appropriate selection of the threshold. Assuming that the accuracy of this method can be further refined and improved in the future, the result of estimation by this method should be helpful for us to estimate the amount of waste and the diffusion of polluted water.

5 CONCLUSION

We developed a method to estimate altitude in old satellite images without stereo pairs. As a result, the method was shown to be able to analyze detailed geographical features in a comparatively narrow area. Additionally, we showed that the estimation result of geographical features by this method is similar to the geographical features presumed by a field survey by boring, etc. Although this method still has limitations in accuracy, it is a very powerful tool to analyze old geographical features that have no DEM using satellite images.

In the future, the method will be improved by doing high-speed, highly accurate analysis by the selection of improvements of the prior distribution that consider the fractals, etc. of natural geographical features, integration of the method of dividing the area, and a more suitable learning algorithms. Moreover, the analysis constitutes a possible method for a large area considering the boundaries in the divided area.

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