

IMAGE CLASSIFICATION FROM CATEGORY PROPORTIONS AMONG MIXELS

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Abstract

A method for image classification based on category proportion estimation is proposed. In this method all pixel in a remotely sensed imagery are assumed to be mixed pixels (Mixel's), and are classified to most dominant category. Among the Mixel's, there exists unconfidential pixels which should be categorized as unclassified pixels. In order to discriminate them, two types of criteria, Chi square and AIC, are proposed for fitness test on pure pixel hypothesis. Experimental result with a simulated dataset show an usefulness of proposed classification criterion compared to the conventional maximum likelihood criterion and applicability of the fitness tests based on Chi square and AIC.

Key words: Mixel, Category proportion, Classification into maximum proportion category, Fitness test.

1. INTRODUCTION

The conventional image classification methods such as maximum likelihood method, minimum distance method and so on have to be assumed that each pixel is pure pixel. In general, however, a pixel in a remotely sensed imagery contain the multiple information from the different categories, such pixel is called mixed pixel (Mixel). The conventional classification methods do not consider the mixel, so the classification result from such method is worse because of misclassified pixel and / or unclassified pixel (Inamura, 1987).

In this study, to establish more accurate classification method, the method which each Mixel is classified into the largest proportion category among Mixel along the idea that all pixels in a remotely sensed imagery are regarded as Mixel's. And to discriminate unclassified pixel from classified pixel, the unclassified limit on the basis of the fitness test of pure pixel hypothesis. To verify the proposed method and to compare with maximum likelihood method, the numerical experiment based on simulated data is conducted.

2. CLASSIFICATION THEORY

2.1 Category Proportion

The information of Mixel can be considered as the linear combination of pure pixel value (supervised data) of each category and category proportion as Eq. (1).

$$\begin{aligned} \mathbf{I} &= \mathbf{A} \cdot \mathbf{B} + \boldsymbol{\varepsilon} \\ \mathbf{I} &= [I_1, I_2, \dots, I_M]^t, \\ \mathbf{B} &= [B_1, B_2, \dots, B_N]^t, \\ \mathbf{A} &= \begin{bmatrix} A_{11} & \dots & A_{1N} \\ \vdots & \vdots & \vdots \\ A_{M1} & \dots & A_{MN} \end{bmatrix}, \\ \boldsymbol{\varepsilon} &= [\varepsilon_1, \varepsilon_2, \dots, \varepsilon_M]^t, \end{aligned} \quad (1)$$

where I_i , B_j , A_{ij} and ε_i are observed data in i -th band, category proportion of j -th category, the supervised data of j -th category in i -th band and observation error of i -th band, respectively and superscript t means transpose. In this study, A_{ij} is assumed to be fluctuated as the normal distribution that the average is \bar{A}_{ij} and variable is σ_{ij}^2 , and ε_i is independent from the proportions and it can be expressed by the normal distribution that average is 0 and

variance is $\sigma_{\varepsilon_i}^2$. From above considerations, the probability $P(\mathbf{I}; \mathbf{B})$ when the proportion vector \mathbf{B} is occurred and multispectral vector \mathbf{I} is observed is expressed as Eq. (2),

$$\begin{aligned} P(\mathbf{I}; \mathbf{B}) &= \frac{1}{(2\pi)^{M/2} \sqrt{\det(\mathbf{Z}')}} \exp \left[-\frac{1}{2} (\mathbf{I} - \bar{\mathbf{A}}\mathbf{B})' \mathbf{Z}'^{-1} (\mathbf{I} - \bar{\mathbf{A}}\mathbf{B}) \right] \\ \mathbf{Z}' &= \begin{bmatrix} \text{VAR}_1 & \dots & \text{COV}_{1M} \\ \vdots & \vdots & \vdots \\ \text{COV}_{1M} & \dots & \text{VAR}_M \end{bmatrix} + \text{diag}[\sigma_{\varepsilon_1}^2, \dots, \sigma_{\varepsilon_M}^2] \\ \text{VAR}_i &= \mathbf{B}' \mathbf{S}_i \mathbf{B} \\ \text{COV}_{kl} &= \rho_{kl} \sqrt{\text{VAR}_k \text{VAR}_l} \\ \mathbf{S}_i &= \text{diag}[\sigma_{i1}^2, \dots, \sigma_{iN}^2] \\ \bar{\mathbf{A}} &= \begin{bmatrix} \bar{A}_{11} & \dots & \bar{A}_{1N} \\ \vdots & \vdots & \vdots \\ \bar{A}_{M1} & \dots & \bar{A}_{MN} \end{bmatrix} \end{aligned} \quad (2)$$

where ρ_{kl} is correlation between band k and l . The desired proportion maximize above $P(\mathbf{I}; \mathbf{B})$ and the proportion has following constraints (Matsumoto, Terayama and Arai, 1992).

$$\begin{aligned} 0 < B_j &\leq 1, \quad (j=1, \dots, N), \\ \sum_{j=1}^N B_j &= 1. \end{aligned} \quad (3)$$

From the estimated proportion, the pixel is classified into the largest proportion category, it is called **Maximum Proportion Criterion (MPC)**.

2.2 Unclassified Limit

The conventional image classification methods have their own unclassified limits which is based on their own classification criterion. In this section, the unclassified limit based on the MPC is described. The meaning which a Mixel can be classified into a certain category is such Mixel can be described by the model that has much constraint. This is called **Pure Pixel Hypothesis**. To verify this hypothesis, the fitness test is applied. In this study the two kinds of fitness tests are proposed.

2.2.1 χ^2 Square Test It is assumed that there are two models π_1 (degree of freedom is n_1) and π_2 (degree of freedom n_2) and π_1 is a special case of π_2 ($n_1 < n_2$). $P(\pi)$ is define as the likelihood of model π and the logarithmic ratio of likelihood

χ^2 is defined as follows.

$$\chi^2 = -2 \ln \left\{ \frac{P(\pi_1^*)}{P(\pi_2^*)} \right\}, \quad (4)$$

where superscript * is the maximum likelihood estimate of the model. The χ^2 is asymptotically expressed by χ^2 distribution $\chi(n)$ which the degree of freedom is $n = n_2 - n_1$ (Takane, 1980). The fitness test of model π_1 is conducted by the comparison between χ^2 and the percentile value of the χ distribution $\chi(n; \alpha)$ with α of significant level.

For the unclassified limit of MPC, π_1 is the pure pixel which contains the information from the largest proportion category (degree of freedom is 0) and π_2 is the Mixel (degree of freedom is $N - 1$, N is the number of the categories). The unclassified pixel is defined as follows.

$$\begin{cases} \chi^2(N-1; \alpha) \leq \chi^2 & \text{Unclassified,} \\ \chi^2(N-1; \alpha) > \chi^2 & \text{Classified.} \end{cases} \quad (5)$$

The value of χ is large when $P(\pi_1)$ is small, so the number of unclassified pixel become large when α is large.

2.2.2 AIC test The value of AIC (Akaike's Information Criterion) of model π : $AIC(\pi)$ is defined as follows.

$$AIC(\pi) = 2n - 2 \ln[P(\pi)] \quad (6)$$

The model π which minimize the $AIC(\pi)$ is the best model to describe.

For the unclassified limit of MPC, the unclassified pixel is defined in the case which the value of AIC of the pure pixel is larger than that of Mixel.

3. VERIFICATION

The above methods are verified as following manner.

3.1 Simulated data

3.1.1 The Supervised Dataset As the supervised dataset, the average and variance of 5 categories in 2 bands, and in this case each band assumed to be independent, so the integrated variance - covariance matrix Z' is diagonal. The supervised dataset is shown in Table 1.

3.2.2 Simulated Category Proportion By using uniform random number from 0 to 1, 100 of proportion of each category is generated as in Eq. (7),

$$B_k = \frac{r_k}{\sum_{i=1}^N r_i}, \quad (k=1, \dots, N). \quad (7)$$

where r_k is uniform random number from 0 to 1. This dataset is used as the true data.

3.2.3 Simulated Pure Pixel Data Since the fluctuation of pure pixel data is allowed in this method, the pure pixel data is generated based on random number of multivariate normal distribution (Takane, 1980). In the generation, the variance of the supervised data is scaled by 0.2, 0.4, 0.6, 0.8

and 1.0 to estimate the effect of the variance of supervised dataset.

3.2.3 Observation Error Generation To estimate the degree of observation error, the observation error is generated random number of normal distribution which average is 0 and standard deviation is 0, 2, 4, 6, 8 and 10 [Count].

3.2.4 Mixel Dataset Generation From the previous simulated dataset, 30 types of Mixel datasets are generated based on Eq. (1). Each dataset contains 100 of Mixel data and the category proportion is the same as in any dataset.

3.2.5 Extraction of True Pure Pixel The proposed unclassified limits are affected by the variance of supervised data and that of observation error, in each condition, based on each unclassified limit, the pure pixel is extracted from each dataset. This data is used in the verification of the classification criterion.

3.3 Comparison between χ^2 Test and AIC Test

To make a comparison between 2 kinds of unclassified limit, The number of true pure pixel and ratio of correctly classified limit is calculated. As a significant level of χ^2 test, 1, 5 and 10 [%] are selected.

3.4 Comparison between Maximum likelihood Criterion and Maximum Proportion Criterion

To compared the proposed criterion with conventional one, The ratio of correctly classified pixel from the proposed criterion (MPC) and maximum likelihood criterion (MLC) calculated. As an unclassified limit of MLC, -20, -15 and -10 of logarithmic likelihood is adopted.

4. RESULTS

4.1 Estimation of The Category Proportion

In this study, category proportion is estimated based on maximum likelihood estimation (Matsumoto, Terayama and Arai, 1992). This method is sensitive to the variance of the supervised data and that of observation error, The root mean square error of the estimated proportion (RMSE) is calculated in each Mixel dataset, and to express the effect of variances, mean variance $AVG[\sigma]$ is calculated as follows.

$$AVG[\sigma] = trace[Z'] \quad (8)$$

The RMSE's are shown in Fig. 1. It is clarified that when the mean variance become larger (the variance of the supervised data and / or that of observation error become larger) the RMSE become larger.

4.2 Comparison between 2 Unclassified Limits

4.2.1 The Number of True Pure Pixel In Fig. 2, The numbers of true pure pixel calculated based on the unclassified limits. When the mean variance becomes large, the number of true pure pixel become large. This is because that The likelihood in Eq. (4) or (6) become broad function. In χ^2 test, the number is slightly affected by the value of significant level, and decreases when the significant level

increases. This means that in χ^2 test, the users can control the number of classified pixel by significant level. The number from AIC test is almost the same as in the case of significant level is 10 [%] of χ^2 test.

4.2.2 The Ratio of Correctly Classified Pixel In Fig. 3, the ratio of correctly classified pixel (the number of correctly classified pixel / the number of selected pure pixel) based on the unclassified limits. The result shows that the 2 unclassified limits are almost the same but in the χ^2 test which the significant level is small the ratio become small because of many selected pure pixel.

4.3 Comparison between the Criteria

Fig. 4 shows the ratio of correctly classified pixel from MLC and MPC. In MLC, when the unclassified limit is large (-10), the ratio is always zero because there are no selected pure pixel, and the other 2 cases of MLC show the ratio which is up to 40 [%]. On the other hand, the ratio from MPC is about 10 [%] higher than that from MLC. This shows the higher classification accuracy of MPC than MLC because of the consideration of the Mixel.

5. CONCLUSIONS

The previous results lead to following conclusions. By considering the Mixel, the classification criterion which each pixel is classified into the maximum proportion category can classify the remotely sensed imagery more accurately than maximum likelihood criterion. And as the unclassified limit of this criterion, the fitness test of pure pixel hypothesis is suitable.

6. REFERENCES

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(*: Original text written in Japanese.)

Table 1 Average and Variance of the Supervised Data

		1	2	3	4	5
A	PC1	97.8	162.4	127.3	60.9	107.8
V	PC2	62.2	135.1	162.0	100.9	187.7
V	PC1	160.4	841.1	185.7	94.0	178.2
R	PC2	309.9	681.3	430.4	329.3	586.2

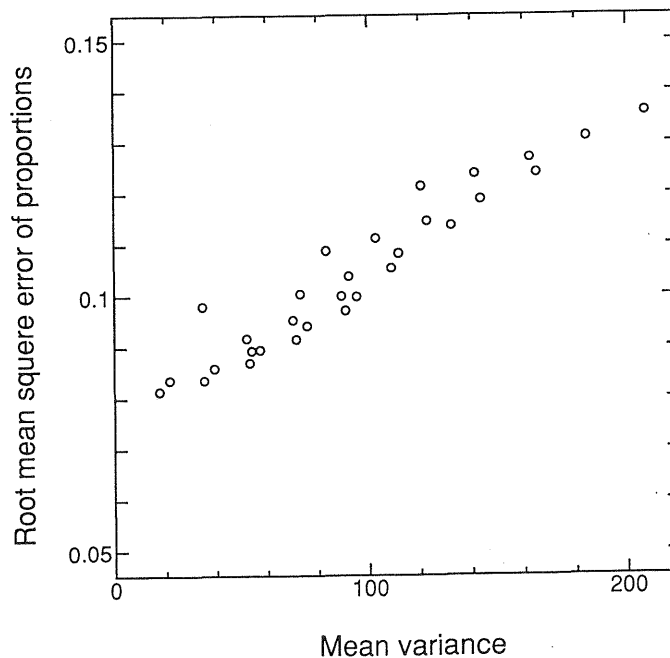


Fig. 1 RMSE of Estimated Category Proportion

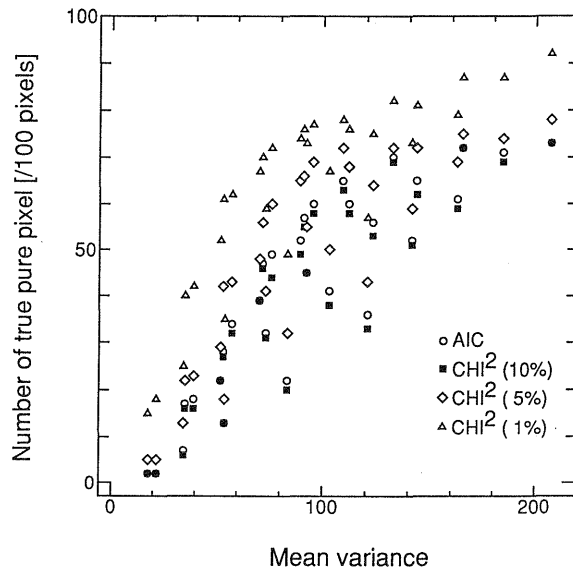


Fig.2 Number of True Pure Pixel

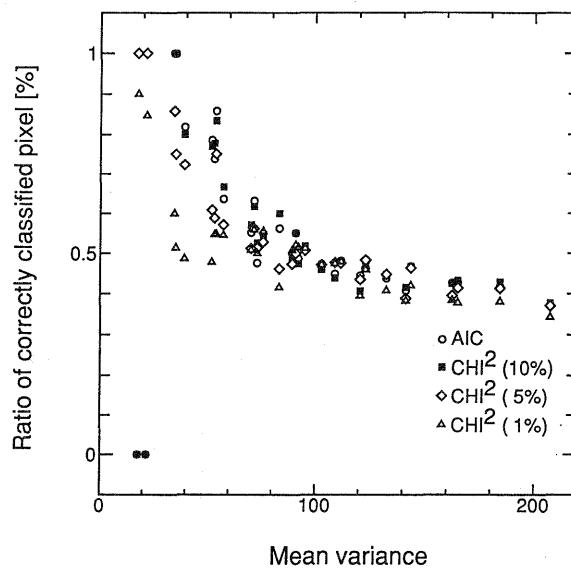


Fig. 3 Ratio of Correctly Classified Pixel (from various unclassified limit)

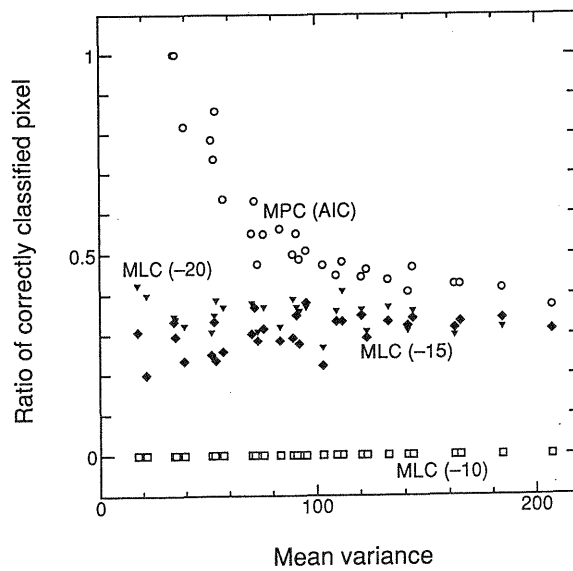


Fig. 4 Ratio of Correctly Classified Pixel (from various criteria)