LAND-COVER CLASSIFICATION OF REMOTELY SENSED DATA USING KALMAN FILTERING

Shinshu University Member of JSCE, Iwao OKUTANI
Shinshu University Non Member, ○Haoxiang WU

1. INTRODUCTION

The conventional techniques of land-cover classification of multispectral remotely sensed data, such as maximum likelihood and linear discriminant function model, are that a pixel is necessarily classified into one category even if it is actually composed of different categories (i.e., a mixed pixel) and the reflectance of spectral bands for each category is estimated by selection of training sets that represent typical examples of each land-cover class. Those methods exist misclassification problem of mixed pixels, which is one of the restricting factors of the classification accuracy of remotely sensed data.

Since the conventional classification models can not be used satisfactorily in processing mixed pixels, in our research, a new model was set up by means of the Kalman filtering theory. The new model can decompose mixed pixels which contain multiple information from the different categories, getting proportion of each category, but also can identify the reflectance of spectral bands for each category, not requiring a special selection of sample pixels (training sets).

2. METHODOLOGY

(1). Identification model for categorical reflectance of spectral bands

Since it can be assumed that the response of each pixel, in any spectral band j, includes the influence induced by m categories, its resulting reflectance value y_j can be seen as a linear combination of the responses of each component supposed to be in the mixed target. Relating to each small area unit k, the basic mixture model can be formulated as follows:

$$y_j(k) = r_1(k).x_{j1}(k)+\cdots+r_m(k).x_{jm}(k)+e_j(k)$$

j=1,⋯,N (band numbers)

where

$y_i(k)$: reflectance of the j-th spectral band
$r_i(k)$: proportion of the mixture component for the i-th category
$x_{ji}(k)$: reflectance of the j-th spectral band for the i-th category
$e_j(k)$: noise term for the j-th spectral band

The above formulation can be seen as an observation equation. The assumptions are that there is only small change of the reflectance from one target unit k to the next of its neighbors. A state equation can be derived as the following structure.

$$x(k+1) = x(k) + v(k)$$

The vector $e(k)$ and $v(k)$ were assumed as the output noise and input noise and were white noise sequences described as follows:

$$E[v(k)] = 0; \quad E\left[v(k)\cdot v(k)^T\right] = R_1$$
$$E[e(k)] = 0; \quad E\left[e(k)\cdot e(k)^T\right] = R_2$$

Where E[•] denotes the expectation, and R_1 the variance and covariance of $v(t)$ and R_2 the variance and covariance of $e(t)$. Thus, Kalman filtering theory can be applied[1]. An algorithm form of the model is then given as

$$\hat{x}(k|k) = \hat{x}(k-1|k-1) + K(k)\cdot\left[y(k) - \Lambda(k)\cdot\hat{x}(k-1|k-1)\right]$$

where

$$K(k) = S(k)\cdot\Lambda^T(k)\cdot\left[\Lambda(k)\cdot S(k)\cdot\Lambda^T(k) + R_2\right]^{-1}$$
$$S(k) = P(k-1) + R_1$$
$$P(k) = S(k) - K(k)\cdot\Lambda(k)\cdot S(k)$$

where $K(k)$ denotes the gain matrix of Kalman filtering algorithm, $S(k)$ and $P(k)$ the variance and covariance matrix of the estimation error of $x(k)$ before and after the $y(k)$ is given. $\hat{x}(k|k)$ is referred to as the filtered estimate of $x(k)$ using $y(k)$.

(2) The estimation model for categories

Let the reflectance of spectral bands given by the average value of the estimates $\hat{x}(k|k)$'s be denoted by $H=(h^T_1, h^T_2,\cdots, h^T_m)^T$ with h_{ji} as the j-th element of h_i. With the similar consideration as identification model, the algorithm form of the estimation model estimated proportion of categories $z(k)= (z_1(k),\cdots,z_m(k))$ can be given as follows:

$$\hat{z}(k|k) = \hat{z}(k-1/k-1) + \bar{K}(k)\left[y(k) - H\hat{z}(k-1/k-1)\right]$$
$$\bar{K}(k) = \bar{S}(k)\cdot H^T\cdot\left[H\cdot\bar{S}(k)\cdot H^T + \bar{R}_2\right]^{-1}$$
$$\bar{S}(k) = \bar{P}(k-1) + \bar{R}_1$$
$$\bar{P}(k) = \bar{S}(k) - \bar{K}(k)\cdot H\cdot\bar{S}(k)$$

3. APPLICATION AND ANALYSIS

Application of the new model by means of Kalman filtering was accomplished using TM data of six spectral bands (TM1~5, TM7, 107-36,28/10/1993), and study area selected in

Odawara city of Kanagawa Prefecture.

(1). Identification of the reflectance of spectral bands and estimation of area proportion for each category

Using TM data and proportion of the categories in each small area unit in the training site, the reflectance of spectral bands for each category was determined by the identification model. As an example, the change of the reflectance of TM7 band for five categories calculated in size of 800m×800m area units is exhibited in **Fig.1** by way of showing the convergent features. The results show the reflectance of spectral bands is stably converged in the latter parts of calculation steps (called convergent range here), from which the reflectance of TM bands for each category was drawn out.

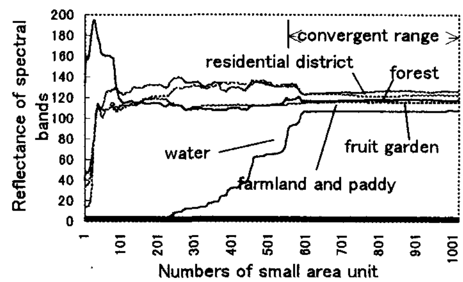

Fig.1 Change of the identified category reflectance of TM7 band with the number of shifting small area unit

The area proportion of each category in each small area unit in the test site was estimated by the estimation model using the convergent values as the reflectance. The results revealed that all classification error indices are improved by Kalman filtering model compared to three existing models(as in **Table 1**.).

Table 1. Comparison of the classification accurary based on different error indices

	Kalman filtering	Quadratic programming	Linear discriminant	Maximum likelihood
RME	0.8833	0.9459	0.9985	0.9857
WRE	0.8977	1.3504	1.1301	1.3522
MAE	0.1751	0.2830	0.2359	0.3043
RMSE	0.1666	0.1964	0.2133	0.2449
η	0.7380	0.7086	0.6924	0.6546
ρ	0.7738	0.7450	0.7340	0.6775

The results showed the proposed model is very efficient. Especially by means of identification process it is possible to extract reflectance of spectral bands for categories from a comparatively large area unit of the size around $1km^2$ which can be of a mixture of land-cover information. That means the use of the proposed model would not be restricted by spatial resolution of remotely sensed data. Hence with other remote sensing data of lower spatial resolution, such as MSS, a simillar classification information or accuracy could be obtained by the proposed model.

(2). Extension of the classification

Taking advantage of the identification process of the reflectance in Kalman filtering model, it is be possible to obtain much more land-cover information. In our research a further classification was accomplished with thirteen categories(They were 1: water, 2: paddy field, 3: farmland, 4: grassland, 5: bare-land, 6: fruit garden, 7: forest, 8: sandy land, 9: road and parking lot, 10: railway, 11: concrete building, 12: tile-roofed house, 13: workshop etc. which is not concrete). Since it is impossible to extract the reflectance for some categories in thirteen categories by means of selection of training sets, the reflectance for thirteen categories obtained by the identification model was also used in the three existing models employed here for evaluating efficiency of Kalman filtering model.

The results showed that a relatively higher accuracy of classification is achieved by Kalman filtering model in spite of the fact that thirteen land-cover categories were classified. That is very significant to improve accuracy of classification for required number of categories in the real life survey and to achieve much more information of land-cover from remotely sensed data. It should be reminded that by using the conventional models only, it is hardly possible to get any information for thirteen classes of categories for lack of the categorical reflectance characteristics.

4. CONCLUSION

The results showed obviously the efficiency of the new model established by Kalman filtering theory for land-cover classification of remotely sensed data. The new model has made it possible to overcome the problem of extracting reflectance of spectral bands for some specific categories, such as road and concrete building and so on, a problem that dominates accuracy of the classification. Furthermore, the model has a considerable advantage in application, being not limited by spatial resolution of remote sensing data, and making much more classes of categories to be classified possibly.

REFERENCES

1) Sorenson, H.S.: Kalman Filtering: Theory and application, IEEE Press, 1985