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# Proposal of a New Index for Plant Characteristics

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**Abstract**

In previous research a singular value decomposing method with some restraint conditions was used to estimate unknown endmembers and coverage in agricultural land. However, it is limited to the ideal case in which observed spectra don't include noise. Hence it is necessary to verify the feasibility of this method to spectra obtained from agricultural area.

In agricultural area, two cases are assumed: observed spectra have a large and a small deviation. If observed spectra have a large deviation, it is more difficult to estimate endmembers. However estimating endmembers is possible using the singular value decomposing method even if observed spectra have a large one. Consequently, it is showed that this method is applicable to even real agricultural land.

Additionally, a new index of plant characteristic was proposed. NDVI (Normalized Difference Vegetation Index) has used in evaluating plant characteristic as usual, however it is affected by coverage significantly. Some researches have reported that NDVI expresses the plant characteristic when the influence of coverage can be neglected. In this study, the influence of coverage was removed to express degree of plant activity numerically.

**Key words**: Endmember, IM-NDVI, Normalized Difference Vegetation Index, Restraint condition, Singular value decomposing method.

## 1.Introduction

Remote sensing is an effective technology because it can measure a wide area in a moment, observe the same area in chronological order and obtain data in digital fashion. For example, with respect to agricultural management, remote sensing makes it possible to understand the situation of crop growth, thus making it easier to improve the application of fertilizer and irrigation by using remote sensing for a large agricultural area. Moreover, production volume becomes predictable by getting information of crop coverage. For these reasons, the use of remote sensing technology to manage large agricultural land is increasing.

Recently, remote sensing technology is used to classify land-use. However, it is difficult to classify when the object is agricultural land. Almost all pixels are characterized by a combination of crop and soil component that is called mixed pixel. For better classification this problem needs to be solved.

To solve the problem, unmixing the mixed pixels and obtaining accurate information such as endmember and coverage is necessary (Ann and Brian, 1996 ; Antonio *et al.*, 2004). It has reported that we can estimate coverage when endmembers are known or observed spectra are quite similar to endmembers. Both cases are ideal and far from actual agricultural land. Generally, homogenous pixels are elusive. In previous research, using a singular value decomposing method and employing some restraints, it was shown that it is possible to estimate unknown endmembers (Awadu *et al.*, 2005). However it was impossible to assert the possibility of estimating them from observed spectra in agricultural land. Hence, estimation of endmembers was carried out using remotely sensed images.

Furthermore, NDVI (Normalized Difference Vegetation Index) has been used in evaluating plant characteristic. However it depends on coverage of plant and plant characteristic. It is important to remove the influence of coverage to evaluate plant characteristic more accurately. Therefore the new index showing plant characteristic was proposed.

## 2.Materials and Methods

The method for estimating endmembers and coverage involves the singular value decomposing method (Sasaki *et al.*, 1983). First, the number of pixels selected from a remote sensing image is defined as K. An observed matrix $X$, an endmembers matrix $S$ and a coverage matrix $C$ is defined as

$$X = \begin{Bmatrix} X_{1,1} & X_{1,2} & \cdots & X_{1,K} \\ & \cdots & \cdots & \\ X_{N,1} & X_{N,2} & \cdots & X_{N,K} \end{Bmatrix}$$

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$$S=\begin{bmatrix} S_{1,1} & S_{1,2} & \cdots & S_{1,L} \\ & \cdots & \cdots & \\ S_{N,1} & S_{N,2} & \cdots & S_{N,L} \end{bmatrix}$$

$$C=\begin{bmatrix} C_{1,1} & C_{1,2} & \cdots & C_{1,K} \\ & \cdots & \cdots & \\ C_{L,1} & C_{L,2} & \cdots & C_{L,K} \end{bmatrix} \qquad (1)$$

where $X_{i,j}$ is a radiance of band $i$ from area $j$ and $N$ is the number of total bands, $S_{i,k}$ is an endmember of band $i$ of category $k$, $L$ is the number of total categories and $C_{k,j}$ is a coverage of category $k$ from area $j$. $X$ is assumed to have a linear relation between $S$ and $C$, and $X$ can be expressed as (2). Next, $X$ is divided into 3 matrices that are expressed as a function of only $X$. The matrices are defined as $U$, $P$, and $V$ that consist of eigenvalues and eigenvectors of $X$. $U$ is defined as the matrix that is made of column-eigenvectors of $X \cdot X^t$. $V$ is defined as the matrix that is made of line-eigenvectors of $X^t \cdot X$ and $P$ is defined as the diagonal matrix that is made of square root of eigenvalues of $X^t \cdot X$. From equation (2) and (3), and using the square matrix $T$, the following equations (4) and (5) are formed:

$$X = S \cdot C \qquad (2)$$
$$X = U \cdot P \cdot V \qquad (3)$$
$$S = U \cdot T \qquad (4)$$
$$C = T^{-1} \cdot P \cdot V \qquad (5)$$

Because endmembers and coverage are never negative, the following restraint is valid:

Restraint 1 Non-negative restraint condition：
$S \geqq 0 \quad C \geqq 0$

From this restraint, some inequalities of factors of $S$ and $C$ can confine unknown matrix $T$ effectively. Hence, it becomes possible to estimate endmembers $S$ and coverage $C$.

It is generally thought that one pixel in remote sensing data of agricultural land includes various proportions of crop and soil. It is comparatively easier to estimate endmember $S$ from observed spectra $X$ because $X$ becomes very similar to $S$. Here, estimation of endmembers is carried out by changing the situation of mixels' coverage.

However, since $T$ has not fully restricted yet, some additional restraints are needed. Hence, the coverage restraint is adopted. Briefly, the sum of coverages in one pixel is about 1.When K=5 and L=2, *Csumi* is defined as $C_{i,1}+C_{i,2}$, and $T$ are restrained *Csumi* are about 1($i$=1,2,3,4,5).

Restraint 2 Csum restraint conditions：$Csumi \fallingdotseq 1$

All estimation results of crop and soil by the singular value decomposing method with Restraint 1 and 2 in the wavelength of 700nm-800nm are likely to have a sudden gradient. Basically, there should be no sudden gradient in the wavelength of 700nm-800nm in soil. Hence, estimation results that have a sudden gradient need to be removed. A gradient of the spectra shape is focused on in order to remove them. Correlation of soil and crop is regarded as an index of similarity of shape. Concretely, $S_{i,1}$-$S_{i+1,1}$ is defined as $dif_{1,i}$ and $S_{i,2}$-$S_{i+1,2}$ is defined as $dif_{2,i}$ and Cor, correlation coefficient of $dif_{1,i}$ and $dif_{2,i}$, is defined as equation(6).( $\overline{dif_{1,i}}$ means average of $dif_{1,i}$ . $\overline{dif_2}$ means average of $dif_{2,i}$ ). When N is 79, the number of each $\overline{dif}$ is 78.

$$Cor=\frac{\sum_{i=1}^{78}\left(dif_{1,i}-\overline{dif_1}\right)\left(dif_{2,i}-\overline{dif_2}\right)}{\sqrt{\left(\sum_{i=1}^{78}\left(dif_{1,i}-\overline{dif_1}\right)^2\right)}\sqrt{\left(\sum_{i=1}^{78}\left(dif_{2,i}-\overline{dif_2}\right)^2\right)}} \qquad (6)$$

Restraint 3 Correlation coefficient restraint condition:
$Cor < 0.2$

Because a sudden gradient leads to high correlation, estimation results with high *Cor* need to be removed. Hence, those with values greater than 0.2 are removed.

In our previous paper, the effectiveness of this method was tested (Awadu *et al.*, 2005). Figure 1 shows the flowchart that is used in this procedure. Figure 2 shows the observed spectra as $X$ and Table 1 shows the coverage as $C$. As it is showed, coverage is changed from 40% to 60%. It is difficult to estimate endmembers because the observed spectra are very similar.

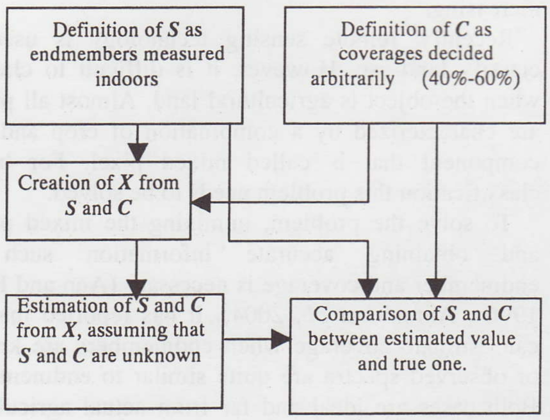



Fig.1. Flowchart of this method.

Figure 3 shows endmembers estimated by the singular value decomposing method with Restraints 1, 2 and 3 in the situation of Table 1. In this figure, the true endmember of soil and the estimated one were very similar, so it was found that the accuracy is high, and the maximum errors from true endmembers are 0.023 in crop and 0.0031 in soil. A significant improvement can be seen. For this reason, with coverage of 40%-60%, the endmember ***S*** could be estimated accurately.

After estimating endmembers of crop and soil, using endmember of crop, IM-NDVI (improved NDVI) was proposed. This index shows pure plant characteristic by removing the influence of coverage. In general, NDVI is calculated with observed spectra as the equation (7), while IM-NDVI is calculated with endmember of crop only as shown in equation (8).

$$NDVI=(NIR-RED)/(NIR+RED) \quad (7)$$
$$IM\text{-}NDVI=(nir-red)/(nir+red) \quad (8)$$

where NIR is a digital value in near infrared of observed spectra, RED is in red spectra, nir is a digital value in near infrared of crop endmember, and red is a digital value representing crop endmember.

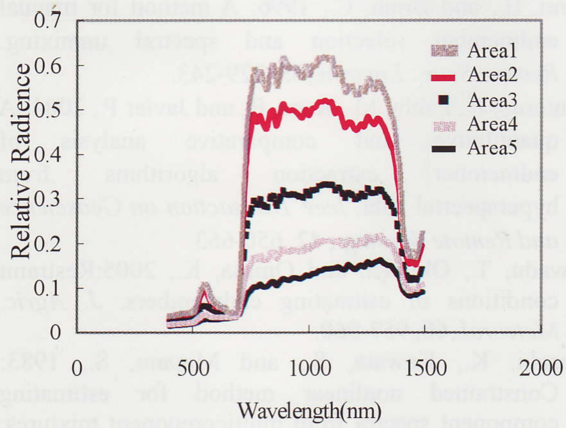


Fig.2. The observed spectra from 5areas.

Table 1. Coverage of each area (40%-60%)

| | Area1 | Area2 | Area3 | Area4 | Area5 |
|---|---|---|---|---|---|
| Crop | 0.41 | 0.52 | 0.45 | 0.6 | 0.55 |
| Soil | 0.59 | 0.48 | 0.55 | 0.4 | 0.45 |

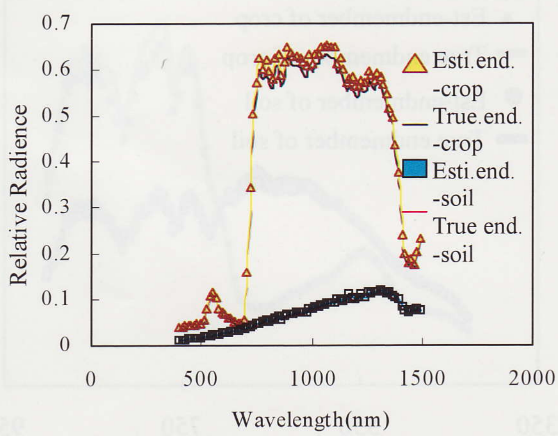


Fig.3. Result of estimation of endmembers by using a new restraint.

## 3.Results and Discussion

The remotely sensed image of Miura peninsula was used in this study as agricultural land and five other areas were selected to get similar spectra (Fig.4). It is much more difficult to estimate unknown endmembers when similar spectra are obtained from the areas. Figure 5 shows the estimation result that is quite accurate. In Fig. 4 two areas surrounded by thick lines are shown. To compare true and estimated endmembers, the observed spectra from the two areas are regarded as true endmembers because NDVI from these areas are the highest and lowest. IM-NDVI can also be calculated with endmembers estimated. Because IM-NDVI doesn't depend on the difference of coverage, it may represent plant characteristic. To know the status of the yield, IM-NDVI can be used as a new index of plant characteristic. Furthermore, a coverage image can be produced in the singular value decomposing method with restraints (Fig.6). Calculating IM-NDVI and coverage, more information in agricultural land was obtained.

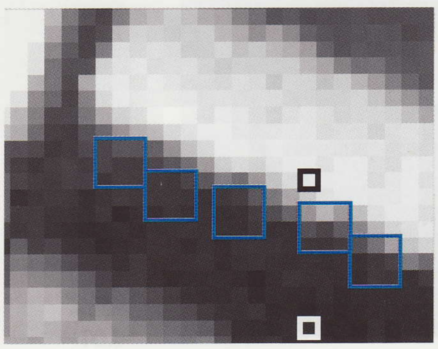


Fig.4. NDVI image in Miura Peninsula and Selected five areas used for estimation of endmembers (areas surrounded by thin lines), and two areas supposed to be pure pixels (areas surrounded by thick lines).

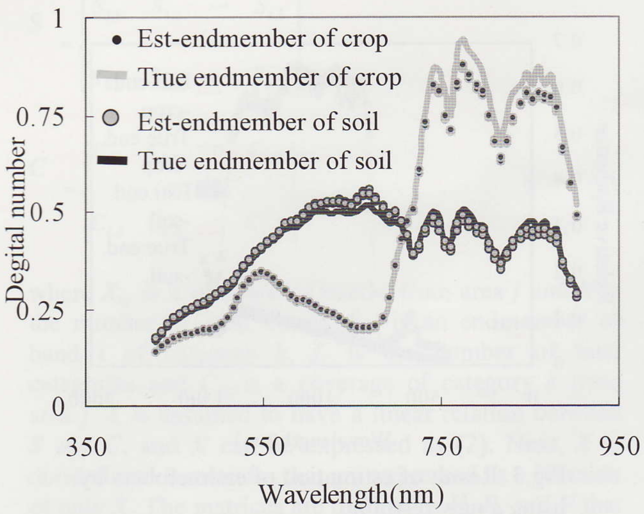
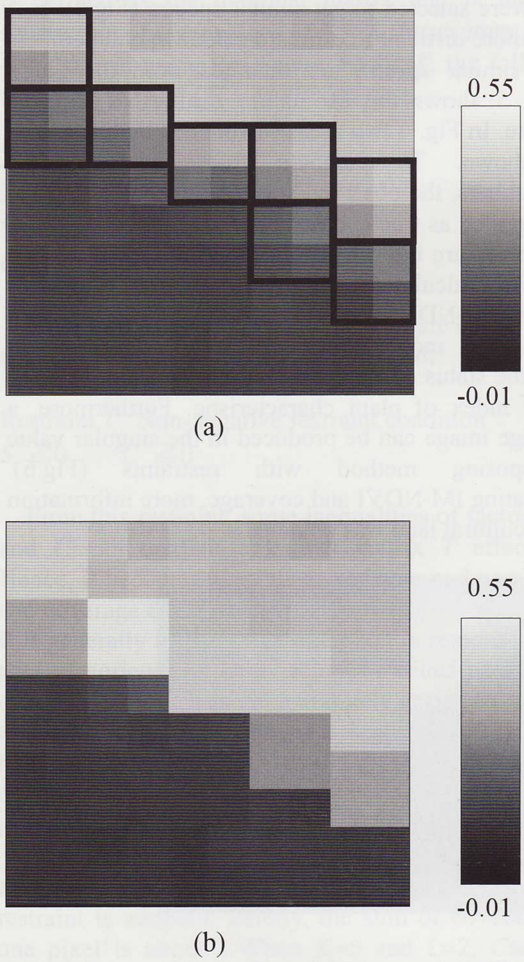



Fig.5. Comparison of estimated endmembers and true endmember.



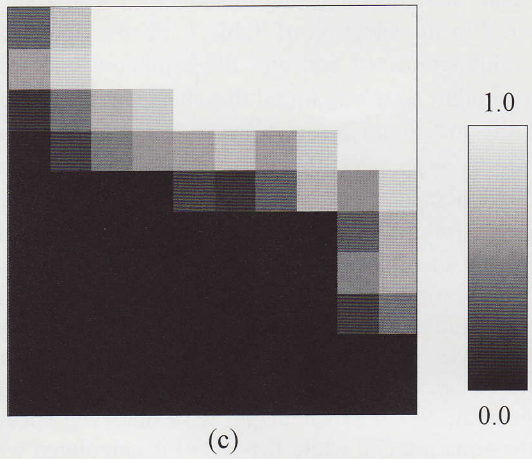




Fig.6. (a): The NDVI image. (b): the IM-NDVI image. (c): the coverage image of Miura Peninsula.

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