Salt-damaged paddy fields analyses using high-spatial-resolution hyperspectral imaging system

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***Abstract*— In agricultural fields, the damage caused by salinized winds is crucial for crops. In order to minimize the damage, it is required to detect the damaged areas and enact the proper procedures in order to save the damaged fields immediately after the disaster. In this paper, we propose indices that can indicate the degree of salt-breezed damages in the early withering-up stage. To detect the indices, high-spatial-resolution hyperspectral data taken in actual damaged paddy fields are analyzed. In addition, the sequential change of hyperspectral data in rice within artificial withering-up experiments is recorded to interpret the fundamental mechanism of the indices. The applicability of the indices for satellite data is also shown by applying them to simulated satellite data.**

Keywords-component; spectroscopy; rice paddy; hyperspectral; salt-damaged; SPOT5; NDVI; NDGI; withering up;

I. Introduction

In August of 2004, an extremely powerful typhoon (0415) Megi struck the coastal area of Yamagata Prefecture, Japan. This typhoon caused the wind blowing from off the sea water to blow onto the land. Due to the lack of the proper procedures after the natural disaster, it seriously damaged the crops in that area. To minimize the effect of the damage resulting from the salinized winds, it is necessary to analyze widespread agricultural fields, and detect the damaged areas at an early stage to deal with the situation.

In order to analyze large agricultural fields with complicated changes, remotely-sensed hyperspectral data become of great importance in recent years [1]. Remotely-sensed data can cover large agricultural fields. Furthermore, the hyperspectral data contain a lot of beneficial information which cannot be observed through our low-resolution RGB system of the eyes directly.

The purpose of this research is to establish the way to detect the damaged areas caused by salinized winds immediately after the disaster. In another point of view, we also intend to use only the data taken after the disaster for damaged area detection, without using the image taken before the disaster.

In this paper, we propose a pair of indices that can detect the damaged areas caused by salinized winds immediately after the disaster. To observe spectral characteristics precisely, a high-spatial-resolution hyperspectral data acquisition system is utilized [2], to be used in actual agricultural fields damaged from salinized winds. Analyzing the hyperspectral image data taken in the fields that suffered various degrees of damage, we propose the indices. In order to prove the validity of indices, we conduct an in-house experiment and observe the sequential withering up process of rice in artificial environment. Analyzing the sequential change of hyperspectral data, the fundamental mechanism of the proposed indices is interpreted. In addition, to apply the indices to satellite images that can cover large area, the simulated satellite data from satellite sensor sensitivities and hyperspectral data in damaged paddy fields are artificially generated. Due to the analyses, the possibility to apply the indices to satellite data is shown.

II. Damaged Paddy Field Analyses

In this section, the data are analyzed to explore indices that can indicate the degree of damage caused by salinized winds. In order to observe the effect of salinized winds to hyperspectral data of rice, we collect data in damaged paddy fields near the coastal area of Yamagata Prefecture, Japan. The data are gathered a week after the typhoon struck.

A. Data Acquisition in Actrual Paddy Fields

The crane-mounted hyperspectral data acquisition system is equipped for taking hyperspectral data in damaged paddy fields [2]. The system contains hyperspectral line sensor, and it is mounted on the tip of crane. Table.1 shows the specification of the data collected by the hyperspectral sensor. It can acquire data in agricultural fields from low altitude about 6m height from the ground surface, and it can generate high-spatial-resolution hyperspectral data. The data taken by the system have comparably advantageous characteristic in the view of data accuracy and spatial resolution to the ones using satellite or airplane for data acquisition. The spectral data are converted to reflectance data using a standard white board for the normalization. Each pixel contains reflectance in every 5nm wavelength between 400nm and 1000nm. The reflectance data are normalized by smoothing among surrounded band before analyses for reducing noise. The mean-spatial resolution in the system is about 6mm^2/pixels.

15 sets of hyperspectral data are collected from (1) 9 no damaged, (2) 3 slightly damaged, and (3) 3 moderately damaged paddy fields a week after typhoon. The mean spectra in each paddy field are used as representative spectra for the analyses.

B. Data Analyses

In agricultural remote sensing, NDVI (Normalized Differential Vegetation Index) is generally used as an index for evaluating crop's state [3]. In addition, we take notice of a process that the color of leaf changes from green to white within withering-up process. Fig.1 shows the visual difference between slightly damaged and moderately damaged paddy fields. According to this phenomenon, we hypothesize that the reflectance might have changed in visible region, especially green (around 550nm) and red (around 670nm) are significant at an early withering-up stage. Therefore, we propose an index NDGI (Normalized Differential Green Index) for indicating the color change in visible wavelength. NDVI and NDGI are defined as in the following equations.

$$\mathrm{NDVI} = (\mathrm{NIR}-\mathrm{R}) / (\mathrm{NIR}+\mathrm{R}) . \quad (1)$$

$$\mathrm{NDGI} = (\mathrm{G}-\mathrm{R}) / (\mathrm{G}+\mathrm{R}) . \quad (2)$$

where NIR is the mean reflectance between 850nm and 900nm wavelength, R is reflectance in 670nm, and G is that in 550nm wavelength.

TABLE I. SPECIFICATION OF HYPERSPECTRAL DATA.

Spectral range	400-1000 nm
Spectral resolution	5 nm
Band number	121 ch

(a) Slightly damaged area. (b) Moderately damaged area.

Figure 1. Visual difference in damaged paddy field.

C. Results of Analyses

Fig.2 shows data points from paddy fields in the characteristic space spanned by 2 indices, defined in (1) and (2). According to Fig.2, all the data points calculated for various damaged paddy fields distribute at high-NDVI region, and they are not so much different from the intact ones. Therefore, it is difficult to detect damaged paddy fields using only NDVI.

However, we can find a tendency that the data taken from no-damaged fields are plotted on a specific line in the 2D-characteristic space (red line in Fig.2). In contrast, data points for damaged fields deviate out of the line. Furthermore, it was found that the distance between the line and data points in the graph indicates the degree of salt damages.

III. OBSERVATION OF WITHERING-UP PROCESS

In this section, we analyze the sequential withering-up process of rice in order to verify the validity of the proposed index. For the analyses, we artificially reenact the experiments to make rice wither up caused by salt and observe the sequential change in the process.

A. Experimetal Methods

2 rice pots are prepared for reenacted experiments. Then, one of the rice pots is exposed with the salt solution blow, and the other one is not processed as a control group for comparison. 2 leaves are picked up as targets in each pot, and

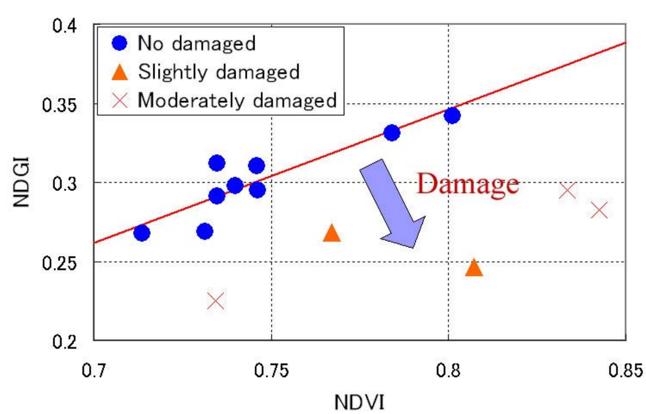
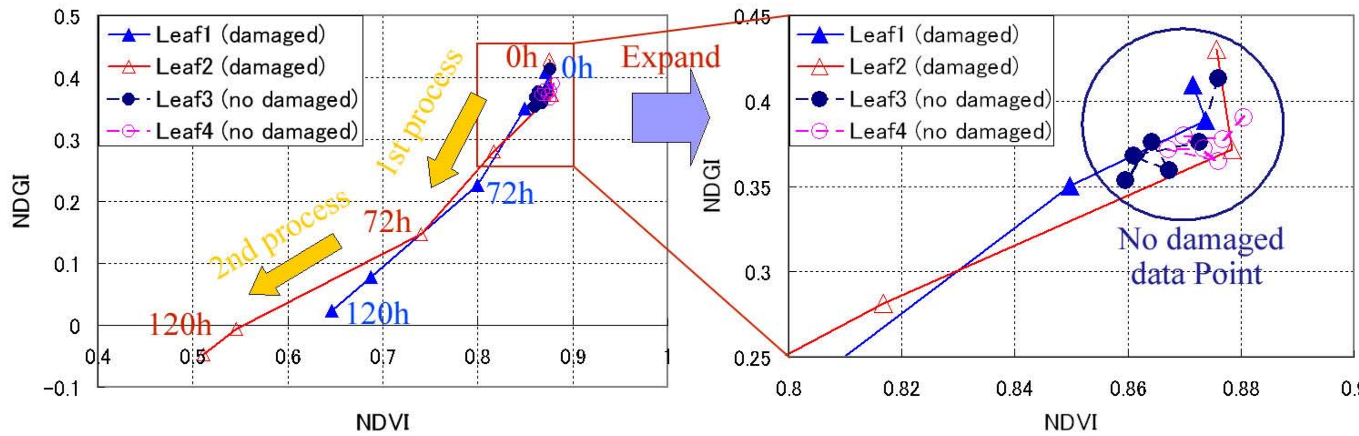


Figure 2. Data point for paddy fields against proposed indices.



(a) Shift of data point against NDVI and NDGI.

(b) Expand graph around starting data point.

Figure 3. Shift of data points from damaged and control leaves.

marked by labels. For the data acquisition, hyperspectral sensor is setup about 50cm above the target, and 4-halogen lamps are used for a light fixture. The target leaves are set on slide table, and the table is slide horizontally for data collection. The hyperspectral data in both pots are collected every day for 5days. The specification of the data generated by the hyperspectral sensor is same as Table.1. The data are converted to the reflectance data and normalized as in the same way as Chapter II A. We extract small part of target leaf, and generate mean spectra in the areas as representative spectra for the analyses.

B. Results of Experiments

Fig.3 (a) shows the data points for target leaves in the characteristic space spanned by 2 indices, defined in (1) and (2). Leaf1 and Leaf2 are extracted from the pot blew by salt solution, and Leaf3 and Leaf4 are control group. According to Fig.3, the data points in the damaged leaves (Leaf1 and Leaf2) shift from right top to left bottom in the graph. In contrast, data points in no damaged leaves (Leaf3 and Leaf4) continue to stay in the starting point (See Fig.3 (b)).

According to the shift of data points in damaged leaves, it become clear that withering-up progress with decreasing both NDVI and NDGI value. In this process, the interesting shift of data points is observed. In the first 72 hours, the decreasing of NDGI is dominant compared to that of NDVI. However, the slope of the trajectory of shifting data points in NDVI-NDGI field is getting flatter according to the progress of the observation sequence.

In the early stage of withering-up process, evaluating the decrease of NDGI is more effective for damage detection when compared to that of NDVI. Thus the proposed index can be effectively used to detect the damaged paddy fields at an early stage.

C. Mechanism of Withering-up Process

Fig. 4 shows the spectra change of Leaf1. According to Fig.4, red reflectance (670nm) increases to be close to green reflectance (550nm) in early withering-up stage. After the red and green reflectance become similar value, both reflectance starts to increase together. In contrast, the near-infrared (850-900nm) reflectance does not show clear difference. According to the change of the spectra by withering-up process, the increase of red reflectance is significant in the early stage. We hypothesize that the increment of red reflectance is caused by the change of ingredients in the leaves. Normall crops contain chlorophyll and carotinoid as ingredients, and their contents can significantly affect the reflectance of crops. In our hypotheses, chlorophyll is destroyed in early stage of withering-up process, and carotinoid is followed later. Chlorophyll have characteristic that absorb red band, and reflect green and NIR, whereas carotinoid mostly reflect NIR. At an early stage of the plant decay, even after the decomposition of the chlorophyll, reflectance of NIR might be kept at a high level. When a small increment in the red reflectance is observed, NDVI will not be changed significantly, because the amount of NIR in the denominator of (1) has a large value. On the contrast, NDGI given by (2) will be significantly changed when R approaches G. Thus the proposed index is much more sensitive to find out the salt damage of the early stage than the conventionally used NDVI.

According to the result of artificial withering-up experiments, it can be estimated that the increment of red reflectance is caused by the process of destroying chlorophyll. Reference [4] shows the change of chlorophyll contents in leaves of broadleaf spices and spectra by cutting branches. In that case, the chlorophyll contents also decrease against the passage of time.

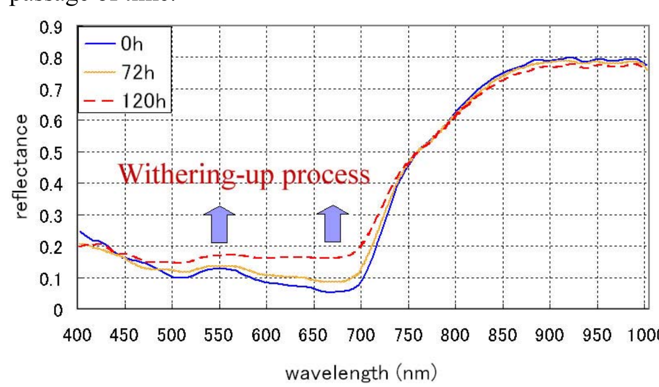


Figure 4. Spectra change of damaged leaves in the passange of time.

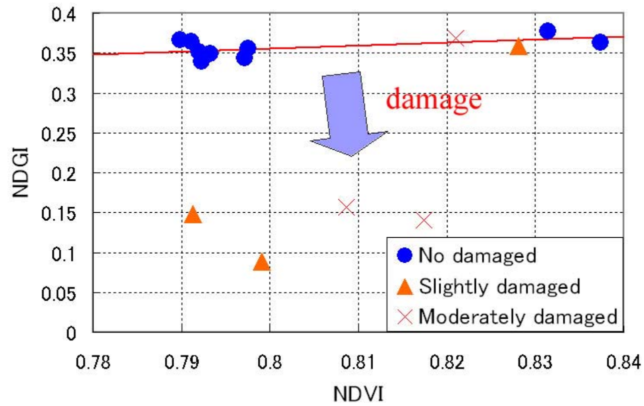


Figure 5. SPOT 5 data point for paddy fields against proposed indices.

IV. APPLICABILITY OF INDICESE FOR SATELLITE DATA

In this section, the applicability of the proposed index for satellite image analysis is evaluated. In order to apply the proposed indices to satellite data, the simulated satellite data are artificially generated from the satellite sensor sensitivities and the hyperspectral data in damaged paddy fields.

A. SPOT5 Data Simulation

Hyperspectral data contain enormous spectral information that covers over wavelengths of receptive range on the satellite multi-spectral sensor. Therefore, the multi-spectral data taken by satellite can be simulated from hyperspectral data using satellite sensor receptions [5]. In this time, multi-spectral data on SPOT5 are simulated as an example.

The SPOT5 simulation data S_j (j : G, R, NIR) are calculated by following equation as reflectance from hyperspectral data.

$$S_j = \sum_{i=1}^{N} R_i \cdot SR_{ij} \Big/ \sum_{i=1}^{N} SR_{ij} \ , \qquad (3)$$

whrere i is the band number, N is the maximum band number, and R_i and SR_{ij} are reflectance and sensor receptions in corresponding wavelengths respectively. Totally 15 set of SPOT5 simulation data are calculated using representative spectra generated in Chapter II A.

B. Evaluation Result

Fig. 5 shows the data points generated by SPOT5 simulation data for paddy fields. According to Fig. 5, the same results as Chapter II C can be observed. Data points in no damaged fields are also located on the specific line, and the data points in damaged fields make small deviation from the line. Therefore, the combined index among NDGI and NDVI can be also applied to satellite data for damage detection in the early stage, as long as the satellite data can be converted to the reflectance values.

The example application to detect damaged agricultural fields caused by salinized winds using proposed index from actual SPOT5 data is shown in [6].

V. CONCLUSION

In this paper, we proposed an index NDGI for detecting damaged agricultural areas caused by salinized winds. Combining it with NDVI, it become possible to estimate the degree of damage in the early withering-up stage. In addition, the applicability of the index for satellite data is analyzed by applying the index to simulated SPOT5 sensor data.

Due to the sequential observation of reenacted experiment, change of spectra and shift of data point by withering up are cleared. It shows the validity of the index for detecting the damage.

According to the characteristic of the index, the parameter of the line that indicates data points in no damaged agricultural fields is crucial for estimating degree of damage. In order to evaluate the degree of damage in any situation accurately, it is necessary to establish the spectral data-base for various kinds of crops and damages.

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