Development of an Integrated System with Remote Sensing Imagery and Field Server Data in Agricultural Land

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Abstract

In this study, we developed an integrated system with remote sensing imagery and Field Sserver data in a cabbage field in Tsumagoi, Gunma Prefecture, Japan. The use of the integrated system enabled us to verify the accuracy of cabbage coverage estimated from various remotely sensed imagery such as AVNIR-2 using a unmixing method, since we were able to see real-time growing cabbages through a Field Server web-camera using the Internet in our laboratory.

Using the developed integrated system, we produced a cabbage coverage map from remotely sensed imagery that provided information on cabbage growth. This type of information could be used for the management of agricultural land, particularly with regard to the application of fertilizer and the prediction of crop production. Our results supported the validity of the use of remote sensing technology to manage agricultural land. The availability and promise of the Field Server system makes an integrated system that also uses remotely sensed imagery a powerful tool.

Using this integrated system we expect to be able to produce maps of various types from remotely sensed imagery in the near future, since Field Servers have sensors such as air temperature, relative humidity, solar radiation, soil moisture, soil temperature, wind direction, wind speed, evapotranspiration, and precipitation sensors that will provide the necessary data.
Keywords: ALOS, Field Server, Unmixing Method

1. INTRODUCTION

In recent years, there has been a improvement in space resolution in the remote sensing technique, which should allow for more accurate land cover classification. However, with agricultural land, the crop area and soil area are mixed together in almost all of the pixels, which are referred to as mixed pixels. Even if space resolution remains at several meters, it is still difficult to accurately classify agricultural land. Thus, it is necessary to obtain more detailed information from the mixed pixels that form the image data of agricultural land acquired by remote sensing. Managing crops is an important component of agricultural management, and thus it is important to be able to assess the condition of the present crop. Since most agricultural land contains a soil category, the fact that the observed spectra show the influence of soil in mixed pixels has posed a problem. Some researchers claim that the NDVI (Normalized Difference Vegetation Index) shows plant characteristics, but this index depends on the coverage of soil rather than on plant characteristics [1], [2]. Crop coverage needs to be estimated by showing plant characteristics without including the soil influence.

Several unmixing methods [3]-[10], which allow a user to estimate the subpixel coverage within each category using linear mixture models, have been proposed. However, it is a problem that the ground truth data acquired by field survey is always necessary to validate the estimated coverages. In general, a great deal of time and money are spent on field surveys.

Recently, the ground truth data acquired by Field Server monitoring systems has gained notice as a substitution for field surveys [11]-[13]. Each Field Server is a multi-functional sensor node that consists of a CPU (web server), a network camera, and various sensors such as air temperature, relative humidity, solar radiation, soil moisture, soil temperature, wind direction, wind speed, evapotranspiration, and precipitation sensors, and a CMOS/CCD camera. The Field Server enables the user to monitor crop and soil information in a remote location in real time through the Internet.

In this study, we developed an integrated system with remote sensing imagery and Field Server data to monitor a cabbage field in Tsumagoi, Gunma Prefecture, Japan. Using the system, we produced a cabbage coverage map without making a field survey.

2. DEVELOPMENT of an INTEGRATED SYSTEM with REMOTELY SENSED IMAGERY and FIELD SERVER DATA

2.1. Field Server

Figure 1 shows the Field Server used in this study. The Field Server is an automatic monitoring system that consists of a CPU (Web server), AD converter, DA converter, Ethernet controller, high-intensity LED lighting, and sensors such as air temperature, relative humidity, solar radiation, soil moisture, soil temperature, wind direction, wind speed, evapotranspiration, and precipitation sensors, and a CMOS/CCD camera [13]. The Field Servers are interconnected by a wireless LAN (Wi-Fi, IEEE802.11b). Digital cameras and web cameras can be connected to the Field Servers, and high-resolution pictures of fields are transferred through Wi-Fi broadband networks and stored on Web servers. The cameras can be remotely controlled by web browsers. The Field Servers can also be used as platforms for network devices and electro-equipment in agricultural land.

Figure 1. Field Server.

2.2. Integrated system with remotely sensed imagery and Field Server data in agricultural land

Figure 2 shows the components of a Field Server monitoring system set up at a cabbage field in Tsumagoi, Gunma Prefecture, Japan, which is northwest of Tokyo and an area well known for cabbage production. We acquired various data such as temperature, relative humidity, solar radiation, soil moisture, soil temperature, wind direction, wind speed, precipitation, evapotranspiration, and CMOS/CCD camera images.

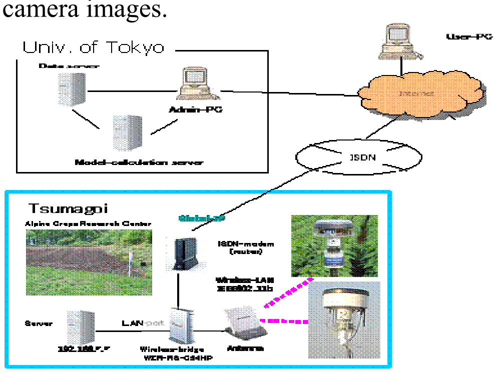

Figure 2. Field Server monitoring system.

Figure 3 shows lysimeter set into the top soil to monitor the growth of cabbage relating to change in soil moisture by precipitation and evapotranspiration, and soil moisture sensors (ECHO-10), which are developed by Decagon Devices, Inc., USA, were installed at the 10-cm and 20-cm depth of both the top soil and the soil of the lysimeter. The data acquired from the sensors traveled from Tsumagoi to a laboratory PC by moving through the Field Server, out its antenna, over the wireless bridge, through the modem, and into the Internet, and it was then distributed by the LAN at our university. Using the Internet, we were able to see real-time data without the frustration of waiting [12].

Figure 3.Lysimeter and soil moisture sensor.

Figure 4 shows some sample images of cabbage growth obtained by a Field Server web-camera. We can see growing cabbages in real-time and monitor the weather occurring in the field.

(a) 12/8/2007

(b) 5/10/2007

(c) 22/10.2007

Figure 4.Images of cabbage growth obtained by Field Server web-camera. (a) Growing period, (b) Preharvest cabbage, (c) After harvesting.

Figure 5 shows examples of meteorological data (air temperature, humidity, amount of radiation, wind speed) and soil information data (soil moisture content and lysimeter weight) on July 1-3. These data can be acquired at our laboratory through the Field Server system and used for prediction of cabbage growth.

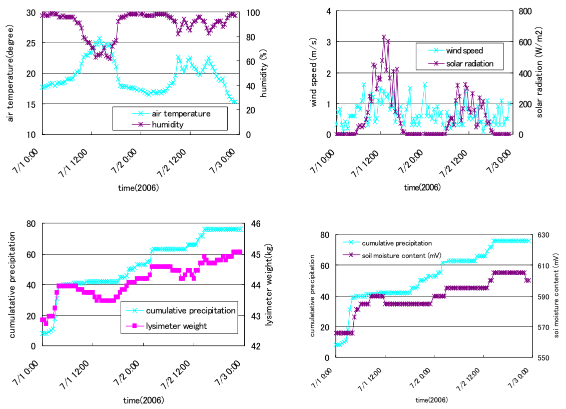

Figure 5.Examples of meteorological data and soil information data on July 1-3 by Field Server system.

We can also acquire remotely sensed imagery of the cabbage field in Tsumagoi by using AVNIR-2 to produce a cabbage coverage map. The imagery contains four multi-spectral bands with a 10m spatial resolution: band 1 (420-500 nm), band 2 (520-600 nm), band 3 (610-690 nm), band 4 (760-890 nm). Figure 6 shows AVNIR-2 imagery acquired on 12 August 2007 and the location of the Field Server monitoring system set up at a cabbage field in Tsumagoi. The accuracy of coverage estimated from AVNIR-2 imagery can be verified by cabbage imagery obtained by a Field Server web-camera.

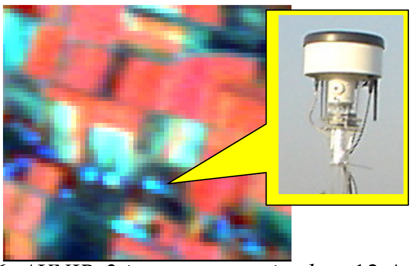

Figure 6. AVNIR-2 imagery acquired on 12 August *2007 and the location of the Field Server monitoring system set up at a cabbage field in Tsumagoi.*

3. Mapping Cabbage Coverage Using the Integrated System

Although the spatial resolution of AVNIR-2 imagery is 10×10m, the categories of cabbage and soil can be included within a pixel. Therefore, a mathematical model was required to estimate cabbage area in the agricultural land. In this study, we used a linear mixture model [3]-[10] that assumes the linear relation between observed spectra and endmembers, which is the radiance value in a homogeneous pixel (pure pixel). The model was based on AVNIR-2 imagery composed of four bands.

In band **n [1,2,3,4]** of the AVNIR-2 imagery, a pixel value $\boldsymbol{P}$ is composed of the cabbage endmember $\boldsymbol{m}_{\mathbf{cabbage}}$ and the background endmember $\boldsymbol{m}_{\boldsymbol{back}}$, which is given in the linear combination of categories except cabbage[7], [9]. Therefore, $\boldsymbol{P}$ can be expressed as:

$$\boldsymbol{P} = a \cdot m_{cabbage} + (1 - a) \cdot m_{back} \tag{1}$$

where $\boldsymbol{a}$ is the coverage of cabbage within a pixel and is nonnegative.

To estimate cabbage coverage from Equation (1), minimizing of the given criteria is carried out under the constraint of $\boldsymbol{a}$ being nonnegative (Equation (3)), as follows:

$$\left|\boldsymbol{P} - a \cdot m_{cabbage} - (1-a) \cdot m_{back}\right| \rightarrow \min. \tag{2}$$

$$a \geq 0 \tag{3}$$

In this study, the least-squares method was used as an unmixing method to minimize Equation (2). However, it is a problem that the spectral vector of $\boldsymbol{m}_{\mathbf{cabbage}}$ and $\boldsymbol{m}_{\boldsymbol{back}}$ must be known before carrying out the unmixing method.

With respect to the endmember problem, the authors of many studies have estimated endmembers from observed spectra [9], [16], [14]-[18]. In this study, we adopted the simplest method, which was to determine the spectral vector of $\boldsymbol{m}_{\mathbf{cabbage}}$ and $\boldsymbol{m}_{\boldsymbol{back}}$ from pixels in the scene using our own subjective judgment. This is very convenient when using the Field Server system, because it is possible to verify the cabbage coverage estimated by the unmixing method, since we can know the real-time cabbage area by looking at web-camera images, as shown in Figure 4. Thus, if the accuracy of the estimated the cabbage coverage is low, we can select another spectral vector of $\boldsymbol{m}_{\mathbf{cabbage}}$ and $\boldsymbol{m}_{\boldsymbol{back}}$ from pixels in the scene.

Figure 7 illustrate a map of the distribution of cabbage coverage estimated by the unmixing method based on a linear mixture model from AVNIR-2 imagery, which was acquired on 12 August 2007. In the cabbage coverage map estimated by the unmixing method from AVNIR-2 imagery, the estimated cabbage coverage shown within red circles was 30% to 35%. The amounts of estimated coverage was valid when checked against Field Server web-camera image shown in Figure 4(a). Therefore, whole area of cabbage coverage on 12 August 2007 should be estimated accurately by the unmixing method from AVNIR-2 imagery.

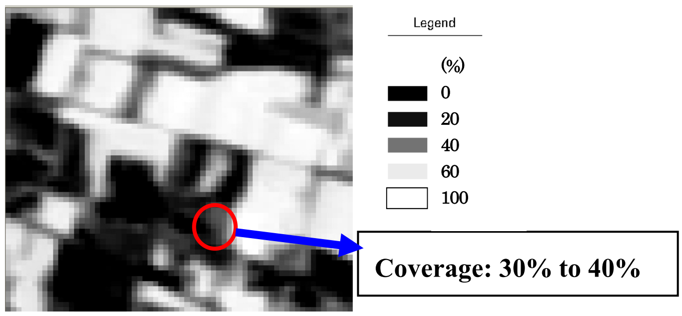

Figure7. Map of cabbage coverage estimated by the unmixing method.

4. DISCUSSION AND CONCLUSIONS

Cabbage coverage was estimated from AVNIR-2 imagery using an unmixing method based on a linear mixture model. In this study, we used our own subjective judgment of pixels in the image to determine the spectral vector (endmember) of each category before carrying out the unmixing method. Therefore, the estimated cabbage coverage had to be verified after carrying out the unmixing method. In general, the ground truth data acquired by field survey, which is costly and time consuming to complete, is necessary to verify the estimated coverage from remotely sensed imagery. To solve this problem, we developed an integrated system with remote sensing imagery and Field Sserver data in a cabbage field in Tsumagoi, Gunma Prefecture, Japan. The use of the integrated system enabled us to verify the accuracy of cabbage coverage estimated from AVNIR-2 imagery using a unmixing method, since we were able to see real-time growing cabbages through a Field Server web-camera using the Internet in our laboratory.

Using the developed integrated system, we produced a cabbage coverage map from AVNIR-2 imagery that provided information on cabbage growth. This type of information could be used for the management of agricultural land, particularly with regard to the application of fertilizer and the prediction of crop production. Our results supported the validity of the use of remote sensing technology to manage agricultural land. The availability and promise of the Field Server system makes an integrated system that also uses remotely sensed imagery a powerful tool.

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ACKNOWLEDGEMENT

This research is conducted under the agreement of JAXA Research Announcement (P3410002).

Also, The authors would like to thank the JST because this study was financially supported by JST.

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