DEVELOPMENT OF AGRICULTURAL MONITORING SYSTEM WITH REMOTE SENSING IMAGERY AND FIELD SERVER DATA

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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 enable us to verify the accuracy of cabbage coverage estimated from various remotely sensed imagery such as AVNIR-2 and QuickBird using a unmixing method, since we can see real-time growing cabbages through a Field Server web-camera using the Internet in our laboratory.

Also, the accuracy comparisons of the cabbage coverage estimated from AVNIR-2 and QuickBird imagery using an unmixing method were carried out to increase the amount of remote sensing data obtained at different levels of spatial resolution on different observation days. The accuracy rates of the cabbage coverage estimated using an unmixing method from AVNIR-2 and QuickBird imagery were almost the same. This result is very interesting, because it shows that we may be able to evaluate cabbage coverage using remote sensing data obtained at different spatial resolutions on different observation days. Thus, it would be possible to use different remote sensing imagery systems to evaluate cabbage conditions during the growing period using this proposed method.

Using the developed integrated system, we can produce a cabbage coverage map from remotely sensed imagery that provides 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. Furthermore, 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.

1. INTRODUCTION

In recent years, the spatial resolution of remote sensing techniques has improved, which should allow for more accurate land cover classification. However, with agricultural land, the crop areas and soil areas are mixed together in almost all of the pixels. Such pixels are referred to as mixed pixels. Even if the spatial resolution remains at the level of 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 system, and thus it is important to be able to assess the crops current condition. Since most agricultural land contains soil and crops, the fact that the observed spectra show the influence of soil in mixed pixels has created a problem (known as the mixed pixel problem). Some researchers claim that the Normalized Difference Vegetation Index (NDVI) 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 while excluding the influence of soil.

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, ground truth data must be acquired by field survey to validate the estimated coverages. In general, a great deal of time and money are spent on field surveys (this is known as the field survey problem). To resolve the mixed pixel and field survey problems, Oki et al. [11] have proposed an integration method to estimate crop coverage with high-spatial-resolution QuickBird imagery using an unmixing method and the ground truth data acquired by the Field Server monitoring systems. The use of the Field Server monitoring systems enabled us to verify the accuracy of the cabbage coverage estimated from high-spatial-resolution QuickBird imagery using an unmixing method, since we were able to see real-time growing crops through a Field Server web-camera using the Internet in our laboratory without engaging in a field survey[12]-[14]. Therefore, we were able to provide information on crop coverage using remote sensing imagery without having to make field surveys.

Another need is for an agricultural monitoring system with remote sensing imagery that can make as many acquisitions as possible during the growing period, to provide information on crop growth to be used for the agricultural management of a large agricultural area, particularly with regard to irrigation and the application of fertilizer. For these reasons, it is very important to measure crop coverage using many remote sensing images.

In this study, we compared the accuracy of the cabbage coverage estimated from AVNIR-2 and QuickBird imagery using an unmixing method. If the accuracy rates of the cabbage coverage estimated using an unmixing method from AVNIR-2 and QuickBird imagery were almost the same, remote sensing imagery obtained at different levels of spatial resolution on different observation days could be used to evaluate cabbage conditions during the growing period. To determine whether this was the case, we used the ground truth data acquired by the Field Server monitoring systems to evaluate the cabbage coverage estimated from AVNIR-2 and QuickBird imagery data with different levels of spatial resolution.

2. 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, and precipitation sensors, and a CMOS/CCD camera [12],[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.

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, and CMOS/CCD camera images.

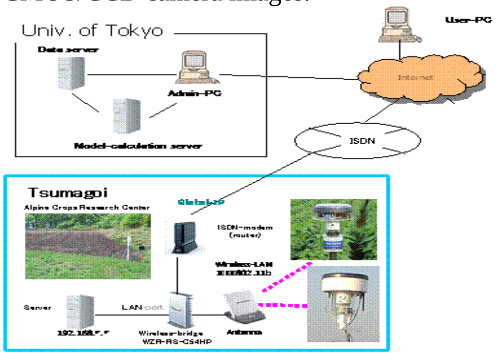

Figure 2. Field Server monitoring system.

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.Llysimeter 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 the accuracy of the coverage estimated using remotely sensed imagery can be verified using cabbage imagery obtained by a Field Server web camera.

(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 changes in lysimeter weight and precipitation from July 1-19. From the change in lysimeter weight, we can see the increase of weight by precipitation and the decrease of weight by dairy evapotranspiration. In addition, we can know that the balance of the lysimeter was destroyed by heavy rain on July 18-19. Such quick reading of a sign is helpful to decrease the risk of data missing during observationperiod. This means that Field Server system is useful for detecting an unexpected-sudden event.

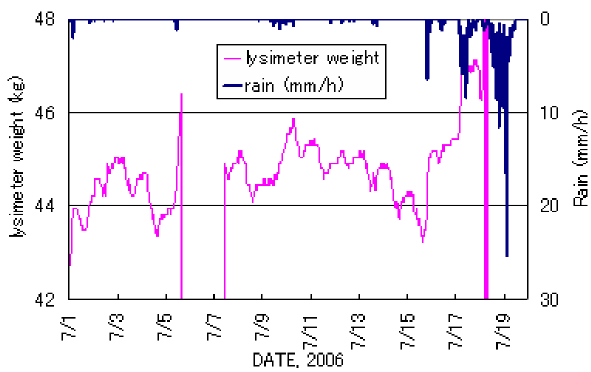

Figure 5.Changes in lysimeter weight and precipitation from July 1-19, 2006.

Figure 6 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 used for prediction of cabbage growth.

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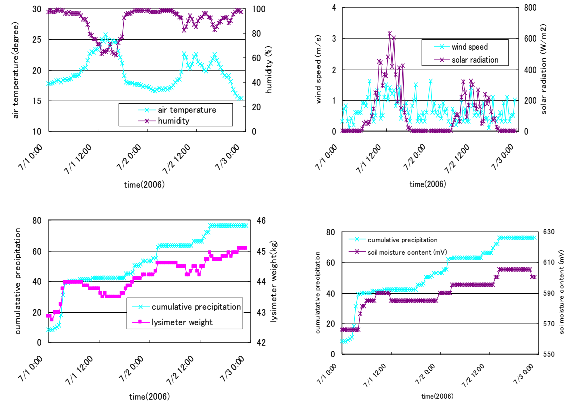

Figure 6.Examples of meteorological data and soil information data on July 1-3 by Field Server system.

2.2. Remotely Sensed Imagery Data

We acquired AVNIR-2 and QuickBird images to carry out accuracy comparisons of the cabbage coverage estimated using an unmixing method, to assemble a collection of remote sensing data obtained at different levels of spatial resolution on different observation days. The AVNIR-2 imagery contains four multi-spectral bands with 10-m spatial resolution: band 1 (420-500 nm), band 2 (520-600 nm), band 3 (610-690 nm), and band 4 (760-890 nm). The QuickBird imagery also contains four multi-spectral bands with a 2.44-m spatial resolution: band 1 (450-520 nm), band 2 (520-600 nm), band 3 (630-690 nm), and band 4 (760-900 nm). Figure 7 shows the analysis area of AVNIR-2 imagery acquired on 12 August 2007 and 22 October 2007, and the QuickBird imagery acquired on 13 June 2007 and 13 August 2007 with the Field Server monitoring system set up at the same cabbage field in Tsumagoi.

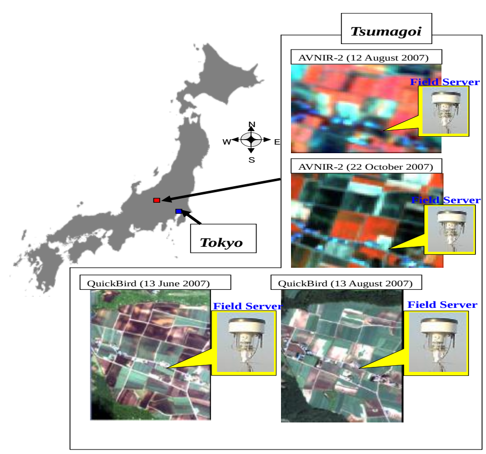

Figure 7. The analysis area of AVNIR-2 imagery acquired on 12 August 2007 and 22 October 2007, and the QuickBird imagery acquired on 13 June 2007 and 13 August 2007 with the Field Server monitoring system set up at same cabbage field in Tsumagoi.

3. ACCURACY COMPARISON OF CABBAGE COVERAGE ESTIMATED FROM IKONOS AND AVNIR-2 IMAGERY

Although the spatial resolution of AVNIR-2 imagery is 10×10 m and that of QuickBird imagery is 2.4×2.4 m, areas covered by cabbage and soil can both be included within a single pixel. Therefore, a mathematical model was required to estimate the cabbage area of the agricultural land. In this study, we used a linear mixture model that assumes a linear relation between observed spectra and endmembers, which is the radiance value in a homogeneous pixel (pure pixel) [3]-[10]. The model was based on AVNIR-2 and QuickBird imagery composed of four bands. The study field had only cabbage as a crop.

In band **n [1,2,3,4]** of the AVNIR-2 and QuickBird imagery, a pixel value $\boldsymbol{P}$ is composed of the cabbage endmember $\boldsymbol{m}_{\mathbf{cabbage}}$, soil1 endmember $\boldsymbol{m}_{\mathbf{soil1}}$, soil2 endmember $\boldsymbol{m}_{\mathbf{soil2}}$, and the agricultural road endmember $\boldsymbol{m}_{road}$, which is given by the linear combination of categories other than cabbage [7],[9]. Therefore, $\boldsymbol{P}$ can be expressed as follows

$$\boldsymbol{P} = a_{cabbage} \cdot m_{cabbage} + a_{soil1} \cdot m_{soil1} + a_{soil2} \cdot m_{soil2} + a_{road} \cdot m_{road} \tag{1}$$

where $\boldsymbol{a}$ represents the cabbage, soil1, soil2, or road coverage within a pixel and is nonnegative. In this study, we set two soil endmembers, since the spectral radiance levels of soil1 and soil2 are sharply different.

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

$$\left| \boldsymbol{P} - (a_{cabbage} \cdot m_{cabbage} + a_{soil1} \cdot m_{soil1} + a_{soil2} \cdot m_{soil2} + a_{road} \cdot m_{road}) \right| \rightarrow \min . \tag{2}$$

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

In this study, we used the least-squares method as an unmixing method to minimize Equation (2). However, the spectral vectors of $\boldsymbol{m}_{\mathbf{cabbage}}$, $\boldsymbol{m}_{\mathbf{soil1}}$, $\boldsymbol{m}_{\mathbf{soil2}}$, and $\boldsymbol{m}_{road}$ must be known before the unmixing method can be carried out.

With respect to the endmember problem, the authors of many studies have estimated endmembers from observed spectra [9]-[10],[15]-[19]. In this study, we adopted the simplest method, which was to determine the spectral vectors of $\boldsymbol{m}_{\mathbf{cabbage}}$, $\boldsymbol{m}_{\mathbf{soil1}}$, $\boldsymbol{m}_{\mathbf{soil2}}$, and $\boldsymbol{m}_{road}$ from pixels in the observed remote sensing image. Thus, the pixels (spectral vectors) in each AVNIR-2 image observed on 12 August 2007 and 22 October 2007, and the pixels in each QuickBird image observed on 13 June 2007 and 13 August 2007 were selected by looking at each scene and deciding whether they were likely pure pixels of any category. 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 determine the cabbage area in real time by looking at the web-camera images, as shown in Figure 4. Thus, if the accuracy of the estimated cabbage coverage is low, we can select another spectral vector from among $\boldsymbol{m}_{\mathbf{cabbage}}$, $\boldsymbol{m}_{\mathbf{soil1}}$, $\boldsymbol{m}_{\mathbf{soil2}}$, and $\boldsymbol{m}_{road}$ using pixels in the scene.

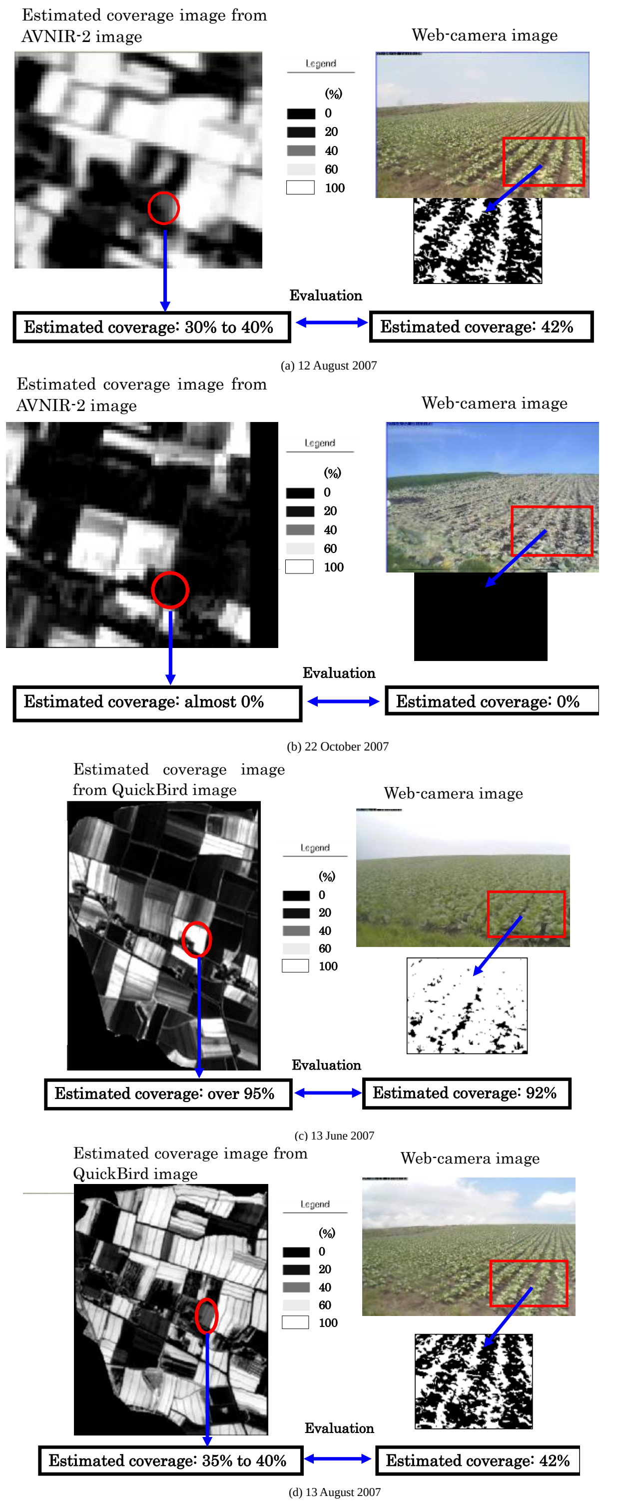

Figure8. The distribution maps of cabbage coverage estimated by the unmixing method based on a linear mixture model from AVNIR-2 and QuickBird imagery,

and cabbage coverage estimated by the ISODATA method from a Field Server web camera.

Figure 8 shows maps of the distribution of cabbage coverage estimated by the unmixing method based on a linear mixture model from AVNIR-2 imagery observed on 12 August 2007 and 22 October 2007and QuickBird imagery observed on 13 June 2007 and 13 August 2007. In these cabbage coverage maps, the estimated cabbage coverage shown within red circles was 30% to 40% on 12 August 2007 and almost 0% on 22 October 2007 for the AVNIR-2 imagery, and over 95% on 13 June 2007 and 35% to 40% on 13 August 2007 for the QuickBird imagery.

Also, the Field Server web-camera imagery was classified into two categories of cabbage and soil by the ISODATA method, which is an unsupervised classification, as shown in Figure 8. The classified cabbage coverage shown within red rectangles was evaluated as 42% on 12 August 2007 and 0% on 22 October 2007 for the AVNIR-2 imagery, and 92% on 13 June 2007 and 42% on 13 August 2007 for the QuickBird imagery. From Figure 8, though there are some errors, it can be seen that the amounts of coverage estimated by the unmixing method were valid when checked against Field Server web-camera imagery. Therefore, the entire areas of cabbage coverage on 12 August 2007 and 22 October 2007 on the one hand and on 13 June 2007 and 13 August 2007 on the other should be estimated accurately by the unmixing method using AVNIR-2 imagery and QuickBird imagery, respectively.

Unlike NDVI, we can evaluate the cabbage coverage directly from remote sensing imagery by using the unmixing method without performing a field survey. Also, the accuracy rates of the cabbage coverage estimated from AVNIR-2 and QuickBird imagery using an unmixing method on 12 August 2007 and 13 August 2007, respectively, were almost the same. In other words, although the cabbage coverage image estimated from AVNIR-2 on 12 August 2007 is coarser than that from QuickBird on 13 August 2007, the value of cabbage coverage estimated by the unmixing method from AVNIR-2 was almost equivalent to the value estimated from QuickBird. This result is very interesting and encouraging, because it shows that we may be able to evaluate cabbage coverage using remote sensing data obtained at different spatial resolutions on different observation days and by different remote sensing sources during the growing period using this proposed method.

4. CONCLUSIONS

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 enable us to verify the accuracy of cabbage coverage estimated from various remotely sensed imagery such as AVNIR-2 and QuickBird using a unmixing method, since we can see real-time growing cabbages through a Field Server web-camera using the Internet in our laboratory.

Also, the accuracy comparisons of the cabbage coverage estimated from AVNIR-2 and QuickBird imagery using an unmixing method were carried out at different levels of spatial resolution on different observation days. We also used the ground truth data acquired by Field Server monitoring systems to evaluate the cabbage coverage estimated from remote sensing imagery data with different spatial resolutions.

The accuracy rates of the cabbage coverage estimated using an unmixing method from AVNIR-2 and QuickBird imagery obtained on 12 August 2007 and 13 August 2007, respectively, were almost the same. In other words, although the cabbage coverage image estimated from AVNIR-2 on 12 August 2007 is coarser than that estimated from QuickBird on 13 August 2007, the value of the cabbage coverage estimated using the unmixing method from AVNIR-2 was almost equivalent to the value estimated from QuickBird. Though we only used two sets of images taken on two days, this result is very interesting, because it shows that we may be able to evaluate cabbage coverage using remote sensing data obtained at different spatial resolutions on different observation days. This shows that we will be able to use remote sensing imagery from different sources to evaluate cabbage conditions during the growing period with this proposed method. As a result, the cabbage coverage map can provide a great deal of information on cabbage growth, which can be used for the management of agricultural land, particularly with regard to the application of fertilizer. Moreover, by obtaining information on cabbage coverage, crop production can be reliably predicted. For example, the harvest time can be expected to be nearer as the value of the estimated cabbage coverage becomes higher.

Furthermore, 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.

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