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Enhancement of NDVI Information from Satellite Imagery by Combining with Low-altitude Sensing

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Abstract: Precision farming (PF) was begun in the latter 20th century. In Japan and other countries, there are many researches on remote sensing which use different kinds of sensors and platforms. One of the applications of the remote sensing in agriculture is to obtain crop status images. Recently, field images can be obtained by QuickBird-2, SPOT and other satellites. However, these satellites are affected by the atmospheric conditions, and also the spatial resolution is fairly low. In addition, the images taken by these satellites have large position errors. And generally, a large number of ground truth reference points must be set to make image calibration successful.

The objective of this study was to develop a reliable field monitoring system combining helicopter-based and satellite-based remote-sensing. Since an ambient illumination (AI) sensor is installed into the sensing system, the effect of atmospheric condition to the satellite image can be compensated. The normalized difference vegetation index (NDVI) of satellite was transformed to reflectance through the image by the unmanned helicopter. In addition, the images taken by the helicopter were also used for calibration of satellite imagery. Therefore, the helicopter-based system will contribute to enhance the satellite-based remote-sensing. In this study, the R^2 value is 0.80 between helicopter-based NDVI and Quickbird2 satellite-based NDVI.

1. INTRODUCTION

Remote sensing is used not only for agricultural environment monitoring but also for many cases such as detecting forest fires, observing disaster circumstances and making a plan for the urban development. Large information is needed for these kinds of cases. To get large information, sensing platforms are necessary to use such as helicopter (Sugiura. R. et al, 2005), airplane and satellite (Saito. G. 2001). These sensing platforms can easily get large information.
Recently, researchers are studying on the remote sensing for various fields. In Japan and other countries, different kinds of sensors and platforms are used on studying remote sensing. Crop information status is one of the applications of remote sensing. Usually QuickBird-2, SPOT5 and other satellites obtain field images and using different methods crop information status can be determined from these field images.

In Japan, in particular, Hokkaido region, satellite image is used for monitoring crop growth in paddy and wheat fields (Okuno. R. et al, 2005). It is used for monitoring the crop and soil status. However, these satellite images are affected by the atmospheric conditions, and also the spatial resolution is low(Fig.1.). And generally, a large number of reference points (ground-truth) must be set to make image calibration successful. It requires much labour and time to get the ground truth data. In order to resolve these problems, combining helicopter image and satellite image is a useful method (Noguchi. N. 2003 ; Niwa. K. 2004). The goal of this research was to normalize and enhance the information on the satellite image such as green, red, near infrared, and normalized different vegetation index (NDVI).

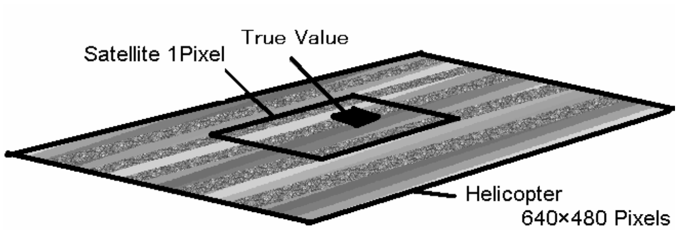


Fig. 1. Difference between satellite and helicopter resolutions

2. SYSTEM SENSING PLATFORM

In this research, unmanned helicopter was used equipped with machine vision. It flies at a low altitude and the machine vision has high resolution. Table 1. shows the specification of the unmanned helicopter. Fig.2 shows the sensing platform. The helicopter's machine vision used in this research was

Duncan tech MS2100 with 640 x 480 pixels and diagonal angle of view is 26.51[°]. Accordingly, its resolution depends on the altitude of the helicopter. The altitudes were 5[m] and 25[m] when imageries were acquired. The field of view of the MS2100 can cover 1.4x1.9 [m] and 7.1x9.4 [m]. Fig.3 shows the optical filter characteristics of MS2100.

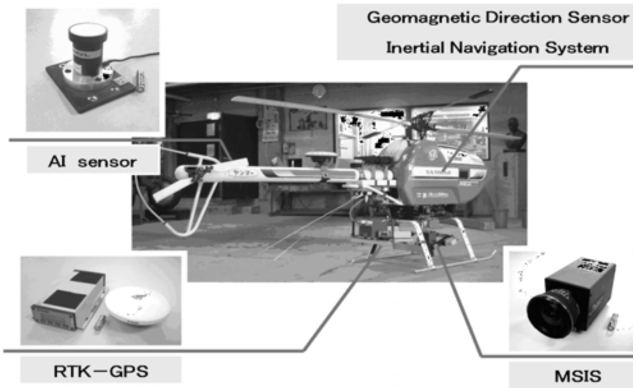


Fig. 2. Helicopter-base sensing system

Table 1. Specification of the unmanned helicopter

Size	Length		2960	[mm]
	Length with loaded main rotor		3950	[mm]
	Height		1150	[mm]
	Weigth		63	[kg]
	Diameter	Main rotor	3380	[mm]
		Tail rotor	660	[mm]
	Payload		294	[N]
Engine	Type		2-cycle Flat 2	
	Displacement		248	[ml]
	Max power		15.8	[kW]

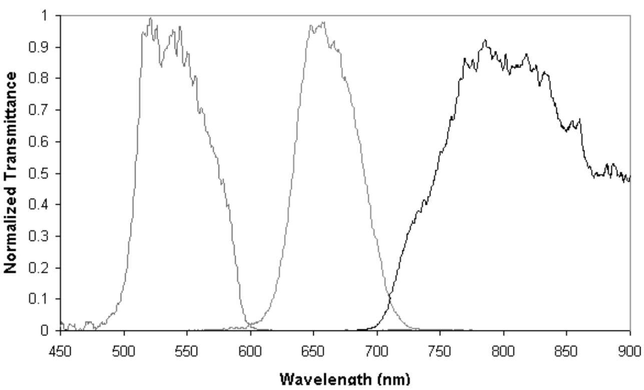


Fig. 3. The filter characteristic of MS2100

3. METHODS

The helicopter images are affected by various factors such as sun light. But the effects can be removed by a correcting equation. Therefore, helicopter image can get the absolute color of the object. The satellite imageries can take the imagery of the wavelength range of blue, green, red and NIR. Corrected color information of satellite imagery was written as *B*. SPOT5 images are corrected by equation (1), and QuickBird-2's are by equation (2):

$$B_{SPOT5} = GL/C \tag{1}$$

$$B_{QuickBird\text{-}2} = C\ GL \tag{2}$$

where *GL* is gray level, and *C* is coefficient of transformation every satellite imagery is given

Corrected color information of helicopter imagery was written as Ref. This information removed the effects of the ambient illumination (AI), exposure time (Exp) and CCD gain (Gain) shown in equation (3).

$$Ref = \frac{C_0 GL + C_1}{(AI + C_2)(Exp + C_3)(e^{C_4 gain} + C_5)} \tag{3}$$

To acquire coefficients (C_0 -C_5), the basic test was performed using a color scale. Using this data, nonlinear regression analysis was used with least square method. Table 2 shows the specification of different sensors.

Table 2. Specification of the sensors

		SPOT5	QuickBird-2	Helicopter
Altitude	[m]	822×10^3	450×10^3	5 - 10
Resolution	[m]	10	2.5	$3 - 15 \times 10^{-3}$
	Blue	-	450 - 520	-
Multi spectral	Green	500 - 590	520 - 600	540
wave range	Red	610 - 680	630 - 690	660
[$\times 10^{-9}$m]	NIR	780 - 890	760 - 900	810
	SWIR	1580 - 1750	-	-

These parameters are explained in following:

$$\begin{aligned} AI &= C_{AI}(E_{AI} + BL) \\ GL &\propto a_{AI} AI + b_{AI} \end{aligned} \tag{4}$$

where AI is the ambient illumination [μmols/cm^2], C_{AI} is a scale factor [μmols/cm^2/mV], E_{AI} is measured voltage [V] and *BL* is black level voltage [V].

$$\begin{aligned} t_{Exp} &= C_{Exp} \cdot Pixels \cdot Exp \\ GL &\propto a_{Exp} Exp + b_{Exp} \end{aligned} \tag{5}$$

t_{Exp} is exposure time [ms], C_{Exp} is a scale factor[ms/line](In the case of MS2100 is 0.065.), $Pixels$ is number of pixels in every each line (In the case of MS2100 is 640) and Exp is a digital value indicating exposure time of MS2100.

$$r = \log_{10}(V_O/V_I) = \ln(V_O/V_I)/\ln 10 = 0.094Gain - 4$$
$$V_O/V_I = e^{0.021644Gain - 0.921034}$$
$$GL \propto e^{a_{Gain}Gain - b_{Gain} + c_{Gain}} \quad (6)$$

r is a input-output gain [db], $Gain$ is a digital value indicating a gain of MS2100.

$$GL = s \cdot GL_{out} - GL_0 \quad (7)$$

GL is a real gray level, GL_{out} is a gray level acquired from MS2100 and GL_0 is an offset of gray level.

Positioning data of the helicopter were measured by real-time kinematic global positioning system (RTK-GPS). Altitude angle of helicopter were measured by inertial measurement unit (IMU). Positioning data of the helicopter imageries were calculated from these data (Sugiura, R., et al, 2003). Both satellite imageries were taken on July 18th in 2004. The helicopter imageries were taken on July 15th in 2004. Table 3 shows about ground truth. "Ear water content" means the amount of moisture of ear.

Table 3. Ground truth

Field size	2.5 [ha]
Planting crops	Wheat
Marker point	15 points
How to measure ear water content	30 samples of each marker, 105℃ & 24 hours drying
Growth stage	About 2 weeks before harvesting

4. RESULTS AND DISCUSSION

4.1 Relationship between satellite and helicopter

In this research, we used the multi-spectral imageries taken by SPOT5, QuickBird-2 and helicopter. These imageries were synchronously taken. As every vision covers the same wavelength range and takes same objects, the color information of the satellite and helicopter images will be integrated. At first, the relation of the information on green, red and NIR were examined. Fig.4 shows the relationship between the sensors. In the figures, there is high correlation in the information about the red and NIR, but there is low correlation about green. The cause is Rayleigh scattering. Rayleigh scattering is the scattering of light, or other electromagnetic radiation, by particles much smaller than the wavelength of the light. It occurs when light travels in transparent solids and liquids, but most prominently seen in gases. The wavelength of green is short. Therefore, light of green range easily scatters compared with red and NIR.

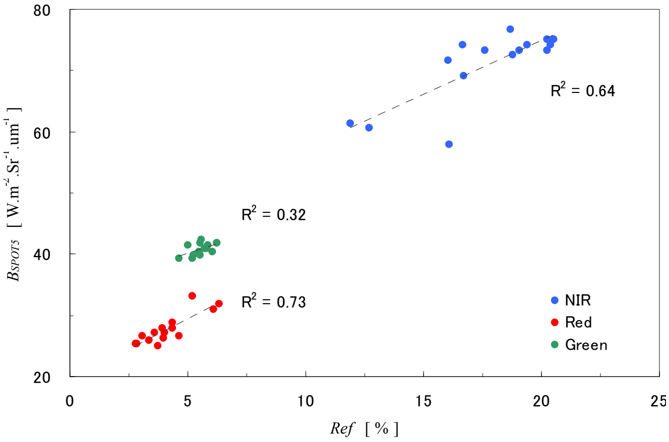


Fig.4. The relationship between SPOT5 and helicopter imageries

In the figures, there is a high correlation in the information about red and NIR, but there is a low correlation about the green. The cause is also Rayleigh scattering. The wavelength of green is short. Therefore, it is easy for green to be scattered.

Next, the relation of the information on NDVI was examined. The NDVI is used for estimating the plant growth. NDVI is the value which used red and NIR. The leaf of the plant absorbs red and reflects NIR (Fig.5).

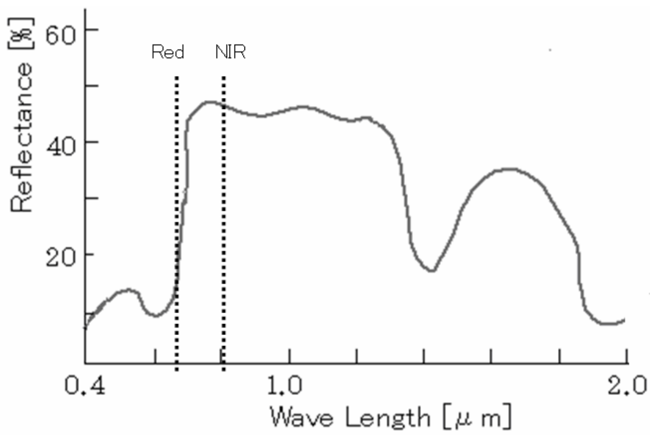


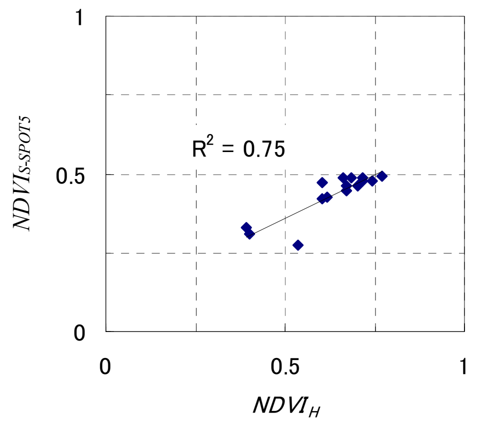
Fig. 5. The spectral reflectance of the leaf

Next, the relation of the information on NDVI was examined. NDVI is the value which used red and NIR. The leaf of the plant absorbs red and reflects NIR. NDVI is used for estimating the plant growth.

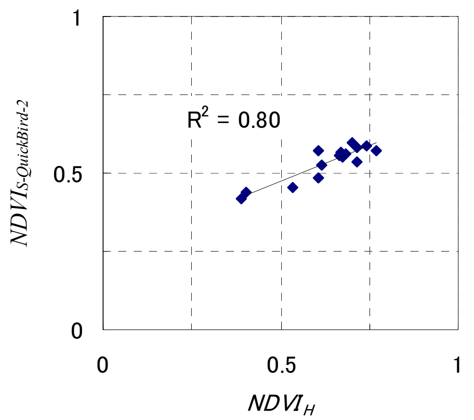
$NDVI_S$ is the satellite-based $NDVI$ given by the equation (8), and $NDVI_H$ is helicopter-base $NDVI$ given by the equation (9).

$$NDVI_S = \frac{B_N - B_R}{B_N + B_R} \quad (8)$$

$$NDVI_H = \frac{Ref_N - Ref_R}{Ref_N + Ref_R} \qquad (9)$$



a) SPOT5 vs. Helicopter



b) QuickBird-2 vs. Helicopter

Fig.6. The relationship between $NDVI_S$ and $NDVI_H$

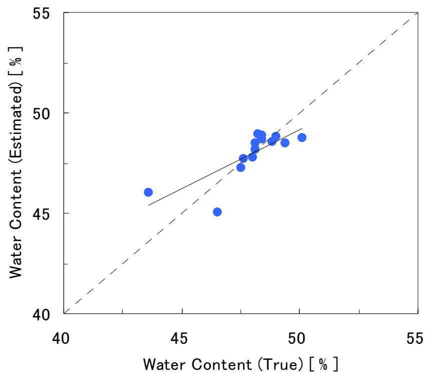
There is high correlation between satellite-based NDVI and helicopter-based NDVI (Fig. 6.). It is possible for helicopter imageries to normalize luminous environment. Therefore, it is possible to normalize color information on the relative satellite imageries in using helicopter imageries.

4.2 Estimation of the ear water content

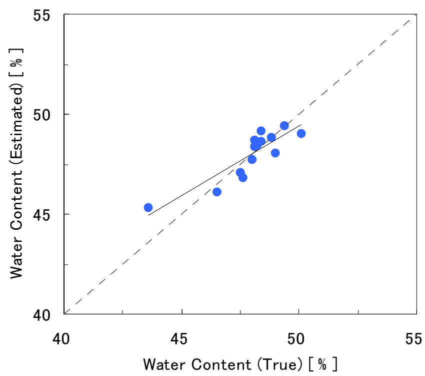
Next, $NDVI_S$ were revised, which was calculated from the satellite image using the helicopter image and estimated growth quantity. An estimated model was made between the helicopter and ground truth. The explanatory variable is the NDVI. If *NDVIs* were changed, SPOT5 can be written as *SPOT5-Heli* and it is same for QuickBird-2, too.

Table 4. The estimated ear water content

Object	Combination	R^2	RMS Error
Ear Water Content [%]	Helicopter - Ground Truth	0.77	0.70
	SPOT5 - Ground Truth	0.70	1.09
	SPOT5-Heli	0.60	0.93
	QuickBird2 - Ground Truth	0.77	0.96
	QuickBird2 - Heli	0.76	0.73



a) SPOT5 – Heli



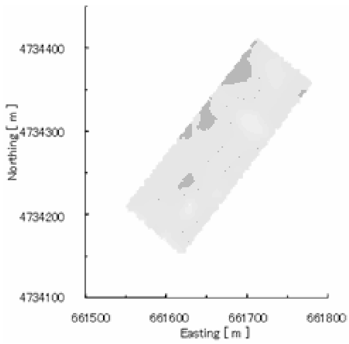
b) QuickBird2 – Heli

Fig.7. Estimated accuracy using NDVI combined satellite imageries and helicopter imageries

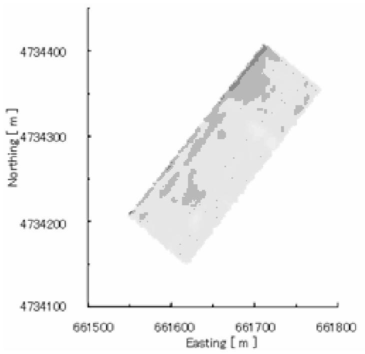
Table 4 shows the relation between ground truth and NDVI. And Fig.7 shows the results of the estimation of ear water content using *SPOT5-Heli* or *QuickBird2-Heli*. The estimation error using only helicopter-based NDVI is very low. And there is a high relationship between NDVI and ground truth. Ear water content can be estimated well with this helicopter remote sensing system. The image resolution of the revised helicopter image became low. But RMS error became small. Therefore, the combination helicopter imageries and low satellite imageries are useful for the improvement of the estimated accuracy of the ground resolution.

4.3 Mapping

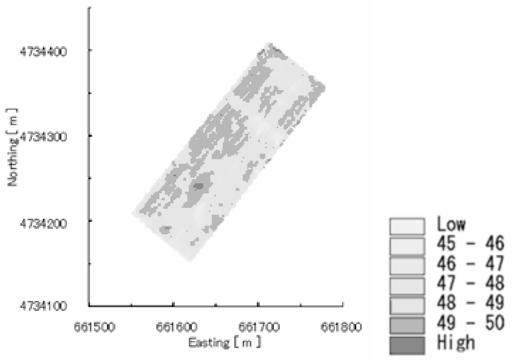
Using the enhanced NDVI parameters (SPOT5-Heli or QuickBird2-Heli), water content map can be generated. Fig. 8 is the ear water content map for one field. The tendency of any map is the same. SPOT5-Heli is better if estimated area is wide. Fig. 9 is the map of wide area. It shows growth quantity of large area. On the other hand, the resolution of QuickBird-2 imageries is better than that of SPOT5, so the map using QuickBird2-Heli can estimate minutely of the big field.



a) SPOT5 - Heli



b) QuickBird2 – Heli



c) Helicopter – Ground Truth

Fig.8. Ear water content map of one field

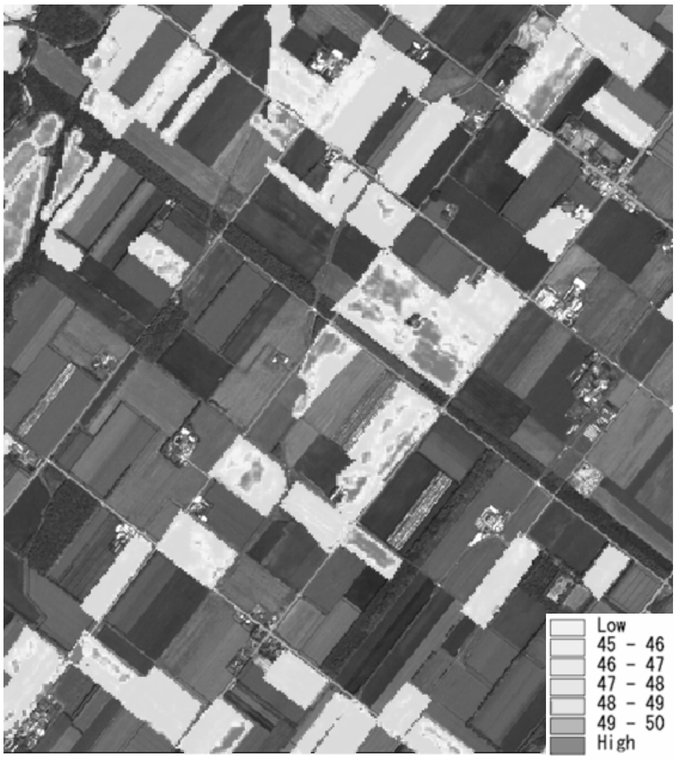


Fig.9. Ear water content map of wide area

5. CONCLUSION

On the color of red and NIR, there is high correlation between satellite imagery and helicopter imagery. Figure 6 suggests that there is also high correlation between satellite-base NDVI and helicopter-base NDVI. Therefore, it is possible to do revision of the colour information on the relative satellite imageries in using helicopter imageries. Using these color information, the field status (ear water content of wheat) can be estimated. Combined Helicopter-base NDVI and satellite-base NDVI, estimation error became low.

6. REFERENCES

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