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.

Table 1. Specification of the unmanned helicopter

<table>
<thead>
<tr>
<th>Size</th>
<th>Length</th>
<th>Height</th>
<th>Weight</th>
<th>Diameter</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2960 [mm]</td>
<td>1150 [mm]</td>
<td>63 [kg]</td>
<td>3380 [mm]</td>
<td>294 [N]</td>
</tr>
</tbody>
</table>

Table 2. Specification of the sensors

<table>
<thead>
<tr>
<th></th>
<th>SPOT5</th>
<th>QuickBird-2</th>
<th>Helicopter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude</td>
<td>822 x 10³</td>
<td>450 x 10³</td>
<td>5 - 10</td>
</tr>
<tr>
<td>Resolution</td>
<td>10</td>
<td>2.5</td>
<td>3 - 15 x 10⁻³</td>
</tr>
<tr>
<td>Blue</td>
<td>500 - 590</td>
<td>520 - 600</td>
<td>540</td>
</tr>
<tr>
<td>Green</td>
<td>610 - 680</td>
<td>630 - 690</td>
<td>660</td>
</tr>
<tr>
<td>Red</td>
<td>780 - 890</td>
<td>760 - 900</td>
<td>810</td>
</tr>
<tr>
<td>NIR</td>
<td>1580 - 1750</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

These parameters are explained in following:

\[
AI = C_{al}(E_{al} + BL)
\]
\[
GL \propto a_{gl}AI + b_{gl}
\]

where \( AI \) is the ambient illumination [μmol/cm²], \( C_{al} \) is a scale factor [μmol/cm²/mV], \( E_{al} \) is measured voltage [V] and \( BL \) is black level voltage [V].

\[
t_{Exp} = C_{Exp} \cdot Pixels \cdot Exp
\]
\[
GL \propto a_{Exp}Exp + b_{Exp}
\]

\( t_{Exp} \) 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.
\[ r = \log_{10}\left(\frac{V_o}{V_i}\right) = \ln\left(\frac{V_o}{V_i}\right)/\ln10 = 0.094\text{Gain} - 4 \]
\[ V_o/V_i = 0.021644\text{Gain} - 0.021034 \]
\[ GL \propto e^{a_{\text{Gain}}+b_{\text{Gain}}+c_{\text{Gain}}} \]  

(6)

\( r \) is a input-output gain [db], \( \text{Gain} \) is a digital value indicating a gain of MS2100.

\[ GL = s \cdot GL_{\text{sat}} - GL_0 \]  

(7)

\( GL \) is a real gray level, \( GL_{\text{sat}} \) 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**

<table>
<thead>
<tr>
<th>Field size</th>
<th>2.5 [ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting crops</td>
<td>Wheat</td>
</tr>
<tr>
<td>Marker point</td>
<td>15 points</td>
</tr>
<tr>
<td>How to measure</td>
<td>30 samples of each marker, 105(^\circ)C &amp; 24 hours drying</td>
</tr>
<tr>
<td>Growth stage</td>
<td>About 2 weeks before harvesting</td>
</tr>
</tbody>
</table>

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 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 red and NIR, but there is 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. 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).

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\[ NDVI_s = \frac{B_N - B_R}{B_N + B_R} \]  

(8)

\[ NDVI_h = \text{given by the equation (9)} \]
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.

\[ \text{NDVI}_H = \frac{\text{Ref}_s - \text{Ref}_g}{\text{Ref}_s + \text{Ref}_g} \]  

(9)

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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 NDVI$_S$ were changed, SPOT5 can be written as SPOT5-Heli and it is same for QuickBird2, too.

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 map using QuickBird2-Heli can estimate minutely of the big field.

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

