Optimizing sensitivity of Unmanned Aerial System optical sensors for low zenith angles and cloudy conditions

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Optimizing sensitivity of Unmanned Aerial System optical sensors for low zenith angles and cloudy conditions
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Introduction
Satellite-based optical imagery cannot provide information on the land surface during cloudy periods. This issue is especially relevant for high latitudes where overcast days and low solar zenith angles are common. Current remote sensing-based models of evaporapotranspiration or carbon assimilation are biased towards clear sky conditions, lacking important information on biophysical processes under cloudy conditions. Unmanned Aerial System (UAS) imagery has great potential to monitor and understand surface fluxes under cloudy conditions

Figure 1. Observed daily diffuse fraction in some of Denmark from 2004 to 2012
Figure 2. Spectral radiance of incoming solar radiation reflected by the Spectralon panel

Objectives
UAS imagery acquired in overcast and cloudy conditions tend to present low brightness and dynamic ranges, and high signal-to-noise levels. Another problem is the influence of land cover types on the signal. For instance, over vegetated areas, even with low irradiance, saturation is reached in the near infrared, while visible channels have low brightness. An individual camera setting for each channel and light conditions can improve sensor sensitivity while preventing saturation. This study aims to optimize the camera exposure settings and radiometric corrections of a multispectral camera to produce high-quality UAV imagery under low but homogeneous irradiance conditions.

UAS sensor
Figure 3. A six band multispectral camera (Tetra Mini-MCA)

Methods and data

Laboratory calibration:
- Instrument:
  - Sphere: a 2m diameter integrating sphere (ISP2000, Instrument Systems)
  - Light source: combined multicolor LEDs (various levels in VIS) and 3 tungsten halogen lamps (various levels in NIR) (flexible light intensities with 11 irradiance levels)
  - Radiance detector: ASD spectroradiometer (Analytical Spectral Devices, Inc.)
- Methods:
  - Geometric correction: retrieve inherent camera geometric parameters
  - vignetting correction: homogenous illumination from the sphere
  - To reduce the radiometric distortion
  - Converting digital number to radiance (L):
- Extended calibration for low radiation conditions

Gain: ON with radiance for specific exposure times
Calibration function: gains and integration times

\[ L = c_1 \times DN + c_0 \]
\[ c_1 = a \times t^b \]

Where \( c_1 \) is the gain, \( c_0 \) is a coefficient related to the dark current, \( t \) is the integration time, and \( a \) and \( b \) are coefficients.

Outdoor experiments:
- Homogeneous targets (Fig. 8): Validate radiance and test optimal exposure settings
  - Camera exposure settings (1, 4, 8, 12ms, Jan 6th, 2017)
- Forest flux sites: Risoe willow bioenergy plantation [11 ha]
- UAS flight campaign: acquire images, validate surface radiance

Figure 4. Filter transmissivity of the six channels of the Mini-MCA camera
Figure 5. Spectral radiance from the integrating sphere
Figure 6. Top cross section view of this setup
Figure 7. Front view of this setup
Figure 8. Experimental plots (left: Teflon, middle: grass, right: soil)
Figure 10. The study sites (Riso)

Table 1. Characteristics of the Mini-MCA multispectral camera

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># of channels (band width)</td>
<td>6 (10 nm)</td>
</tr>
<tr>
<td>Weight</td>
<td>750g</td>
</tr>
<tr>
<td>Geometric resolution</td>
<td>1280 x 1024</td>
</tr>
<tr>
<td>Radiometric resolution</td>
<td>10 bits</td>
</tr>
<tr>
<td>Pixel size</td>
<td>5.2 µm</td>
</tr>
<tr>
<td>Focal length</td>
<td>9.6 mm</td>
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</table>

Table 2. The calibration geometric parameter values for Tetra mini-MCA6 (unit:mm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>470 nm</th>
<th>530 nm</th>
<th>570 nm</th>
<th>670 nm</th>
<th>710 nm</th>
<th>800 nm</th>
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<tr>
<td>F</td>
<td>9.858E+00</td>
<td>9.815E+00</td>
<td>9.805E+00</td>
<td>9.751E+00</td>
<td>9.823E+00</td>
<td>9.895E+00</td>
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<td>Ca</td>
<td>-2.61E-01</td>
<td>-2.63E-01</td>
<td>-2.58E-01</td>
<td>-2.53E-01</td>
<td>-2.61E-01</td>
<td>-2.74E-01</td>
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<tr>
<td>Cy</td>
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<td>-5.12E-01</td>
<td>-4.06E-01</td>
<td>-1.01E-01</td>
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<td>-1.17E-01</td>
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<tr>
<td>R1</td>
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<td>-1.51E-01</td>
<td>-1.22E-01</td>
<td>-1.09E-01</td>
<td>-7.73E-02</td>
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<td>R2</td>
<td>1.27E-01</td>
<td>3.90E-03</td>
<td>5.08E-03</td>
<td>3.44E-03</td>
<td>3.64E-03</td>
<td>1.30E-02</td>
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<tr>
<td>R3</td>
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<td>1.94E-01</td>
<td>1.28E-01</td>
<td>1.29E-01</td>
<td>-1.21E-01</td>
<td>-4.86E-02</td>
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<tr>
<td>p0</td>
<td>8.54E-06</td>
<td>3.52E-05</td>
<td>2.73E-05</td>
<td>5.58E-05</td>
<td>2.54E-05</td>
<td>2.76E-05</td>
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<tr>
<td>p1</td>
<td>-3.71E-05</td>
<td>-3.20E-05</td>
<td>-5.22E-05</td>
<td>-3.72E-05</td>
<td>-4.54E-05</td>
<td>1.41E-05</td>
</tr>
</tbody>
</table>

C and C0 are principal point offset; k1 and k2 are radial distortion coefficients; p1 and p2 are the tangential distortion coefficients.

Results

Figure 9. SNR for different exposure settings and targets under constant illumination for low conditions (irradiance less than 0.1W m-2 sr-1 nm-1)

As Fig. 14 shows, with more exposure time, the SNR increased, but once saturation was reached (SNR>110), the SNR did not increase more. This turning point is the optimal camera exposure setting. Teflon, grass and soil have different combination of optimal exposure settings for each channel. Fig. 15 shows the error for radiometric performance of Tetra Mini-MCA. Errors for grass and soil is high, due to that the exposure time is not optimal. The error for Teflon is within ±8%.

UAS flight campaign
- Place: Risø willow field
- Time: 25-05-2016 11:15 a.m.
- Flying altitude: 80m
- Spatial resolution: 2.95cm/pixel
A UAS flight campaign was conducted to validate the accuracy of radiance estimation from the Tetra mini-MCA.

Figure 16. True color of the multispectral orthophoto and validation of the accuracy of Tetra Mini-MCA radiance estimation with vignetting correction

Conclusion and future work
This study provide a methodology to thoroughly radiometrically calibrate a multispectral camera for low illumination conditions. Outdoor experiments were used to assess the performance for calibration with radiance errors within ±8%. Future work will focus on using the imagery obtained in cloudy and overcast conditions to improve remote sensing based models of evaporapotranspiration or carbon assimilation.

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This study was funded by the smart UAV project from Danish National Advanced Technology Foundation (125-2013-5). Sheng Wang would like to thank the COST ACTION ES1109 (OPTIMAISE), which offers a short term scientific mission to Dr. Pablo J. Zarco Tejada’s lab in Spanish National Research Council.