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 evapotranspiration 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

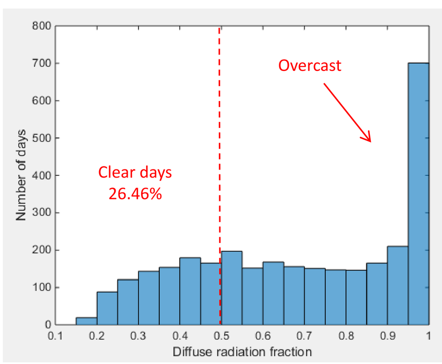

Figure 1. Observed daily diffuse fraction in Soroe of Denmark from 2004 to 2012

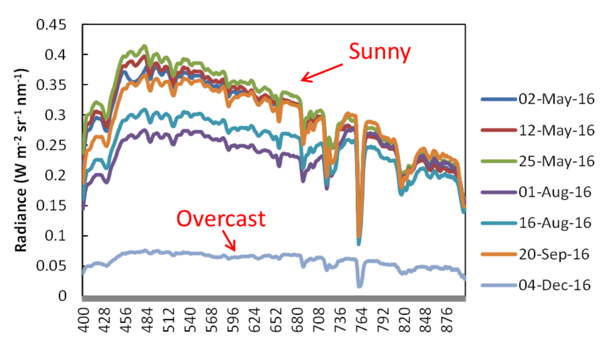

Figure 2. Spectral radiance of incoming solar radiation reflected by the Spectralon panel

Objective

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

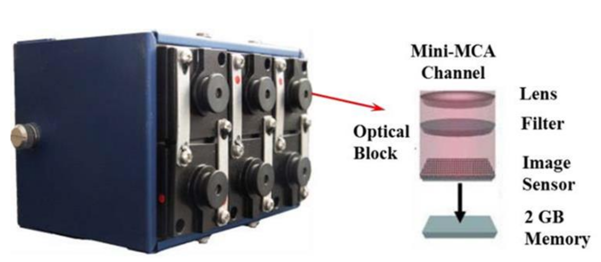

Figure 3. A six band multispectral camera (Tetra Mini-MCA 6)

Table 1. Characteristics of the Mini-MCA multispectral camera

Parameter	Value
Nr of channels (band width)	6 (10 nm)
Weight	700g
Geometric resolution	1280×1024
Radiometric resolution	10 bits
Pixel size	5.2 µm
Focal length	9.6 mm

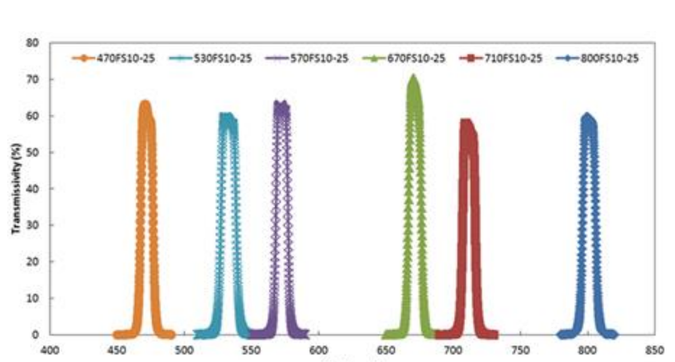

Figure 4. Filter transmissivity of the six channels of the Tetra Mini-MCA6 camera

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 illumination levels)
  - ✓ Radiance detector: ASD spectroradiometer (Analytical Spectral Devices, Inc.)
- Methods:
  - ✓ Geometric correction: retrieve inherent camera geometric parameters
    - o To improve the accuracy of image mosaicking
  - ✓ Vignetting correction: homogenous illumination from the sphere
    - o To reduce the radiometric distortion
  - ✓ Converting digital number (DN) to radiance (L):
    - o Extended calibration for low illumination conditions

Gain: DN with radiance for specific exposure times

$$L = c1 \times DN + c0$$

Calibration function: gains and integration times

$$c1 = a \times t^b$$

Where c1 is the gain, c0 is a coefficient related to the dark current, t is the integration time, a and b are coefficients.

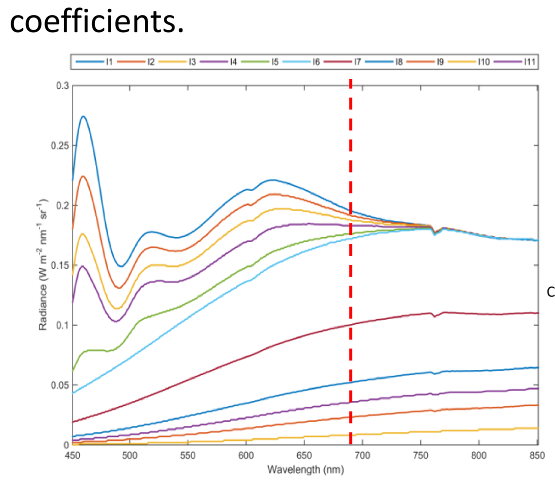

Figure 5. Spectral radiance from the integrating sphere

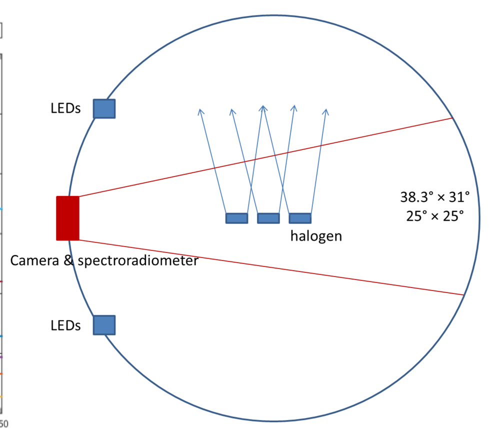

Figure 6. Top cross section view of this setup

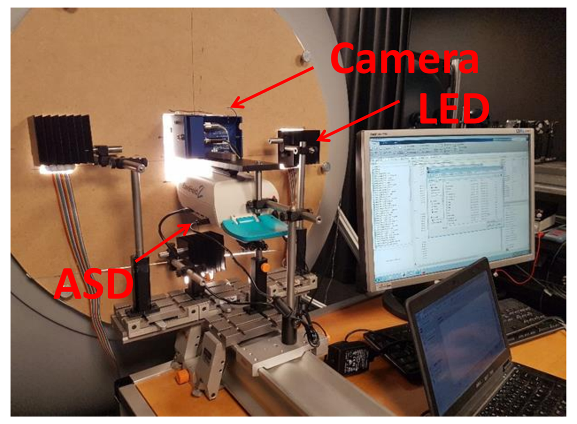

Figure 7. Front view of this setup

Outdoor experiments:

- Homogeneous targets (Fig. 8): Validate radiance and test optimal exposure settings
  - ✓ Camera exposure settings (1, 4, 8, 12ms, Jan 6th, 2017)

Figure 8. Experimental plots (left: Teflon, middle: grass, right: soil)

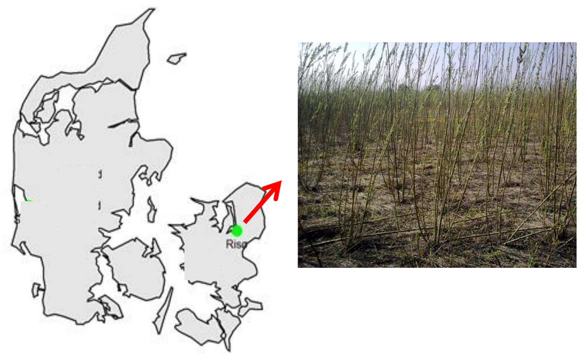

Figure 10. The study sites (Risø)

- Forest flux sites: Risoe willow bioenergy plantation (11 ha)
  - ✓ UAS flight campaign: acquire images, validate surface radiance

Results

Laboratory calibration results

- **Geometric correction**

With pre-calibrated geometric parameters, the accuracy of image mosaicking and the quality of the orthophoto could be improved.

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

Parameter	470 nm	530 nm	570 nm	670 nm	710 nm	800 nm
F	9.89E+00	9.81E+00	9.89E+00	9.75E+00	9.82E+00	9.89E+00
Cx	-2.61E-01	6.38E-01	5.92E-03	7.64E-01	2.81E-01	-1.74E-01
Cy	-6.69E-01	-5.12E-01	-4.06E-01	-1.01E+00	-6.66E-01	1.17E-01
k1	-1.83E-03	-8.15E-04	-1.22E-03	6.09E-05	-7.72E-04	-1.75E-03
k2	1.25E-02	4.90E-03	5.08E-03	-3.44E-03	3.64E-03	1.30E-02
k3	-4.01E-02	-1.34E-02	-1.29E-02	5.94E-03	-1.22E-02	-4.48E-02
p1	8.54E-06	3.52E-05	2.72E-05	3.58E-05	2.54E-05	2.76E-05
p2	-3.71E-05	-3.20E-05	-5.22E-05	-3.72E-05	-4.54E-05	1.41E-05

C_x and C_y are principal point offset; k_1, k_2 and k_3 are radial distortion coefficients; p_1 and p_2 are the tangential distortion coefficients.

Results

Laboratory calibration results

- **Radiometric correction**

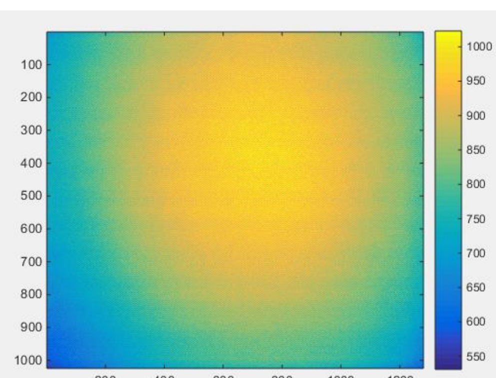

Figure 11. Raw image with the integrating sphere

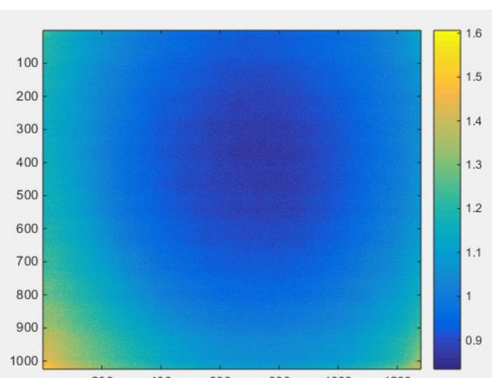

Figure 12. Vignetting Correction factors (correct to the mean value)

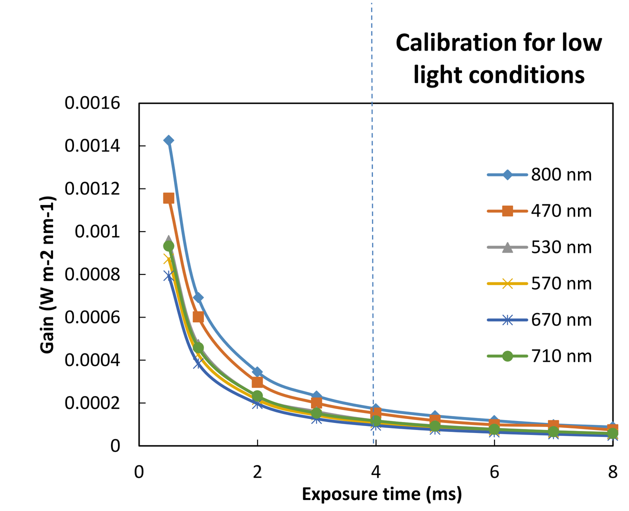

Figure 13. Gain factor for six channels

The lab experiment has radiometrically calibrated Tetra Mini-MCA to the exposure settings ranging from 0.5 to 8ms. Exposure time from 5 to 8ms is mainly for low illumination conditions. With the calibrated gain function curve, measurements with field radiometers prior to flying can be used to establish the exposure time for each channel.

- **Experimental plots**

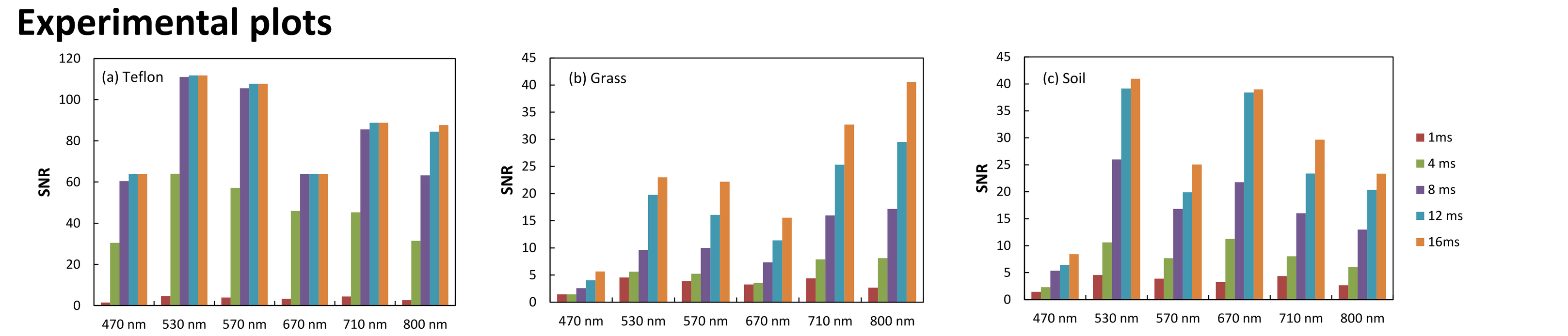

Figure 14. Signal-to-noise ratio (SNR) for different exposure settings and targets under constant illumination for low conditions (irradiance less than 0.1W m-2 sr-1 nm-1)

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%.

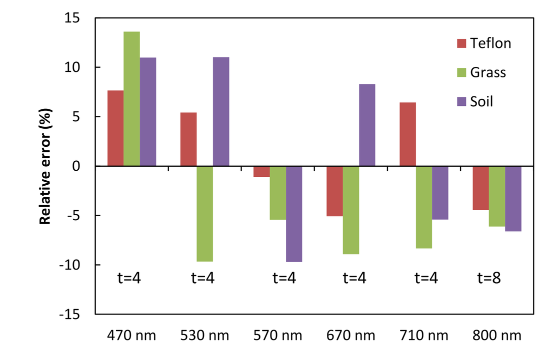

Figure 15. validation of The radiometric performance of Tetra Mini-MCA (t is the optimal exposure time for Teflon. The exposure times for grass and soil are 8ms)

- **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.

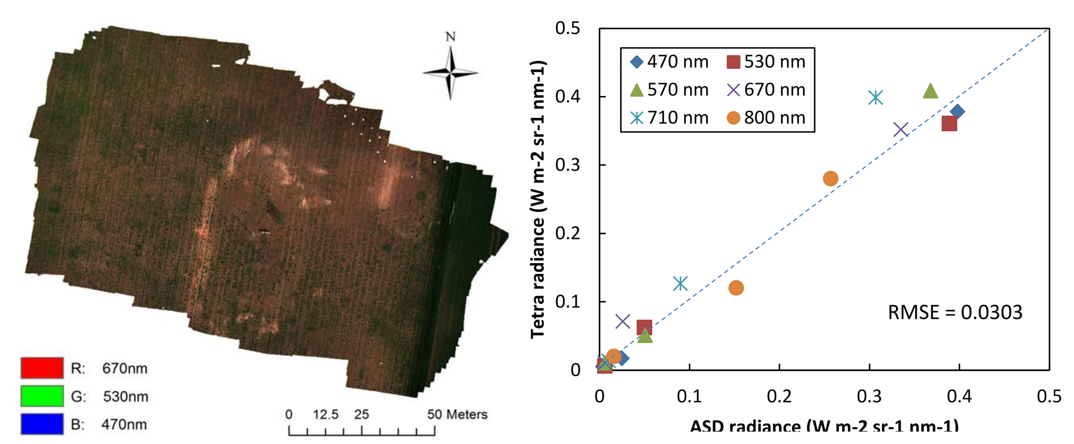

Figure 16. True color of the multispectral orthophoto and validation of the accuracy of Tetra Mini-MCA radiance estimation with vignetting correction

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 evapotranspiration or carbon assimilation.

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