AN OPERATIONAL SOLUTION TO ACQUIRE MULTISPECTRAL IMAGES WITH STANDARD LIGHT CAMERAS: CHARACTERIZATION AND ACQUISITION GUIDELINES

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ABSTRACT:

In order to develop a low-cost and easy to implement technical solution to map inside-field spatial variability, and to explore its relationship with crop conditions, several experiments were conducted using ultra-light aircraft and Unmanned Aerial Vehicle (UAV) equipped with visible and infrared cameras.
The sensors consisted of a ramp of 3 small format digital cameras (EOS 350D, Canon®): one for the visible part of the spectrum, and two modified cameras in order to acquire red edge and near infrared radiations. The images acquisition on the 3 cameras is simultaneous using external triggers and can be activated through the operator remote control on the ground or programmed to be automatically done using an on-board GPS navigation system. On ultra-light aircraft we also add a micro-bolometer thermal camera to the system.
This paper describes the components of this acquisition system and focuses on the geometric and radiometric processing steps necessary for quantitative use of the data.
At an altitude of 500 m this system acquires images with a ground resolution of 8 cm for the visible and near infrared bands and 55 cm for the thermal band. Unmanned Aerial Vehicle common altitude stretches over several tenth of meters up to 500 m and is adapted to the survey of fields of several hectares with very high spatial resolution. Ultra-light aircraft offers a range of altitude up to 1 to 2 km and a larger survey capacity with smaller spatial resolution.
The spectral sensitivity of the cameras was measured using monospectral emittance sources. We worked both on the raw multispectral images and on the computed jpeg standard output. This allowed us to select the best band (or band combination) to produce red edge and near infrared images. We also developed an algorithm to compensate some radiometric distortion in the acquired images, particularly on vignetting effect.
Classical photogrammetric calibration was used in order to measure lens geometry of each camera and evaluate as precisely as possible the coefficients of the lens polynom needed by commercial photogrammetric software.
Several sets of images were acquired over experimental fields in temperate zone (on wheat) and tropical zone (on sugarcane). These images were radiometrically and geometrically corrected used the above elements and are stored as georeferenced stackable images in a Geographic Information System.
The next step for a quantitative use of the data is to compensate changes due to atmospheric and illumination conditions in the image time series.

1. INTRODUCTION

Because they can provide information on large areas with rapid changes, low-cost aerial systems with high spatio-temporal resolution are particularly suited for agriculture and environment applications (Johnson et al., 2004; Sugiura et al., 2005). These systems are composed of a light platform, like an ultra-light aircraft or an Unmanned Aerial Vehicle (UAV), equipped with visible and infrared digital cameras. To utilize the full potential of this technology, the digital cameras can be used as sensors after considering a certain number of technical and scientific points (Tarel, 1995; Stevens et al., 2007).
The objective of this paper is to describe an easy to implement technical solution. We first describe the platform and sensors used, then we present the radiometric algorithms involved in the data processing steps (bands splitting, spectral characterization, vignetting correction), and finally we point out what will be the next steps to get an efficient and cost-effective high resolution imagery system for agricultural and environmental applications.

2. PLATFORMS AND SENSORS

2.1 The Ultralight aircraft module

The multispectral module is made by the assembly of three Canon® EOS 350D digital cameras on a hard-wood mount (Figure 1). These cameras are equipped with the same lenses and are pointing in the same axis, their shutter being synchronized by a single trigger.
This equipment is light enough (2.8 kg) for an hand-help used (Figure 2) or can be mounted inboard an ultra-light

aircraft, the lens pointing through a hole practiced in the fuselage floor.
The ultra-light aircraft was chosen for its slow flight characteristics avoiding « motion blur » when images are taken at a low altitude (below 300 m).


Figure 1. Canon® EOS 350D digital cameras device

The digital cameras are able to collect the radiation in five different bands (blue B, green G, red R, red edge RE and near infrared NIR) thanks to technical adaptations described in details in part 1.3.


Figure 2. Ultralight aircraft device

This cameras device is completed by a thermal imager (B20HSV, Flir Systems®), installed outside the fuselage side and also synchronised with the cameras (Figure 3).


Figure 3. Thermal infrared camera B20HSV, Flir Systems®

2.2 The Unmanned Aerial Vehicle module

Powered by an electric engine driving a pushing airscrew (Figure 4), the UAV is able to reach an altitude of 400 m and to maintain it during half an hour. Its control is supported by an IMU (Inertial Motion Unit) and can be manual, semi-automatic or fully automatic.


Figure 4. UAV designed by L'Avion Jaune Company

This UAV can lift a maximum of 2 kg payload, so that is not powerful enough to get in the air the cameras module described before. It carries only two cameras at a time and the thermal imager cannot fit inboard. So this UAV is generally used to collect only RGB and Near InfraRed images.

2.3 Cameras adaptations

The cameras are « off the shelf » products conceived to be used to get images within the visible light spectrum. As their CMOS (Complementary metal–oxide–semiconductor) detectors are sensitive from ultra violet (UV) to near infrared (NIR) wavelengths, they are manufactured with a visible pass-band filter that keeps UV and NIR from reaching the CCD surface. This equipment needs some adaptations in order to gather information situated outside the visible spectrum.
To modify the spectral sensitivity of the cameras, we first open the cases of two cameras and remove the visible pass-band filter located in front of the CMOS matrix. The filter was then replaced by an optical window transparent to visible and near infrared wavelengths and preserving the same optical path for the light rays.
After this operation the cameras are sensitive above 700 nm and additional filters are added in front of the lenses to obtain the desired spectrum range for the data acquisition: a red-edge filter (L.O.T. Oriel®) centred on 700 nm with a bandwidth of 25 nm at 10% cut, and a near infrared filter centred on 840 nm with a bandwidth of 80 nm at 10% cut (LDP LLC®).

Consequences of the adaptations:

1- A coating is applied on the front lenses for chromatic optimisation; for the modified cameras this coat produces a strong vignetting in the red-edge and infrared bands that has to be compensated.

2- The removal of the filter needs to be followed by a spectral characterization giving the new shape of the response curve of the Bayer matrix. This operation can only be done in a specialized optical laboratory.

3. RADIOMETRIC CORRECTIONS

3.1 Splitting the image bands

The Canon cameras gives their images by the mean of a Bayer matrix where each individual pixel is filtered and thus coded in red, green or blue (Figure 5).
On most of the commercial cameras, an interpolation is applied on the Bayer matrix in order to compute a 3 bands (R, G, B) image (Figure 6), with a realistic appearance for the human eye (logarithmic relation). Furthermore, the radiometric resolution is often lowered during this operation (generally from 12 to 8 bits) and compressed (e.g. JPEG format). Unfortunately, these image processing steps done by the manufacturer software are unknown. To get "spectrally pure" pixel values we had to develop a specific software to get a true linear signal from the RAW images.

R	G	R	G
G	B	G	B
R	G	R	G
G	B	G	B

Figure 5. Bayer matrix example.
This 16 pixels camera includes 4 red, 4 blue and 8 green individual filters. In the RAW format each of these 16 measurement are given (with a 12 bits radiometric resolution for the Canon® EOS 350 D)

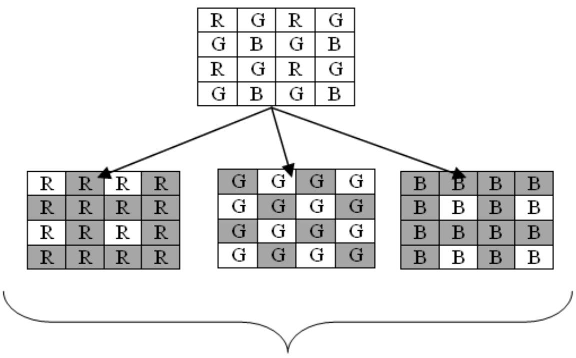


Figure 6. On board computed colour image (interpolated pixels are greyed)

3.2 Characterization of the spectral sensitivity

We carried out the spectral characterization of the original and modified cameras in ONERA laboratory in Toulouse. This characterisation is made with photos of a monochromatic source light. The monochromatic light is made by a tungsten lamp, a diffraction grating and a slot.
The characteristics of this light are: bandwidth of 1.2 nm and a centre precision of 0.1 nm. The measurements are made 5 nm by 5 nm in the visible and near infrared bands, and 2 nm by 2 nm in the red-edge band. The cameras tunings are the same for all the measurements: Shutter speed of 0.067s, relative aperture of f/5.6, sensivity ISO = 100 ASA, and focal of 55 mm.
The software chooses the 100th pixel of the image, ranked by decreasing digital counts. This value is extracted with a software developed by the "Avion Jaune" firm, based on *dcraw* software (Coffin, 2007).
The relative spectral response r has been calculated for a given wavelength λ and a given channel n (RGB) with the following equation:

$$r(\lambda, n) = R(\lambda, n) / R_{max} \quad (1)$$

with

$$R(\lambda, n) = (C(\lambda, n) - C_{black}) / I(\lambda) \quad (2)$$

where R is the spectral response given in digital count and I is the light intensity measured with a diode located at the same distance that the camera (Figure 7). C is the digital count corresponding to channel n. C_{black} is the mean of the obscurity current for the three channels RGB expressed in digital counts.

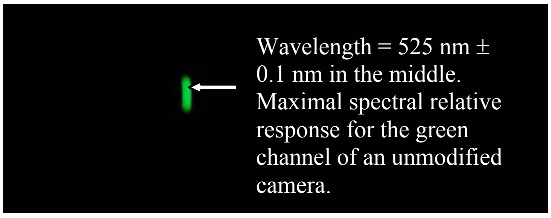
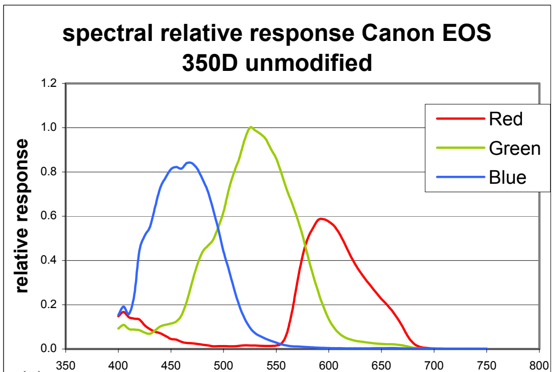
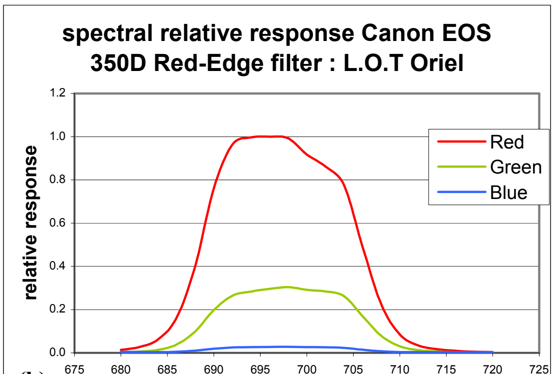


Figure 7. Example of an image of the monochromatic source light.

The relative spectral responses of the red, green, blue, red edge and near infrared bands are represented in Figure 6.



(a)



(b)

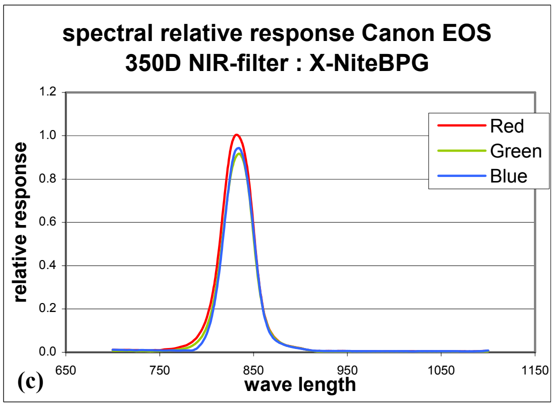


Figure 8. Spectral relative response of an original Canon EOS 350D with visible pass-band (a), a modified body equipped with : a red-edge external filter (b), a near infrared external filter (c)

The relative spectral response in the red-edge showed a stronger dynamic in the red channel. In the NIR, the spectral response is quite the same for the three channels, so we can keep one of those or use the three in order to get the entire resolution of the sensor.

3.3 Vignetting correction

The photography taken in the NIR and the Red-Edge showed some effects similar to vignetting. The strong darkening in the periphery of those images is the result of the interactions between the filter, the frontal lens and the missing of the band-pass filter in front of the matrix. These effects are specific to technologic choices. The correction of this visual effect follows the same principles than the corrections of the vignetting, and is performed with a software developed by the “Avion Jaune” Company.

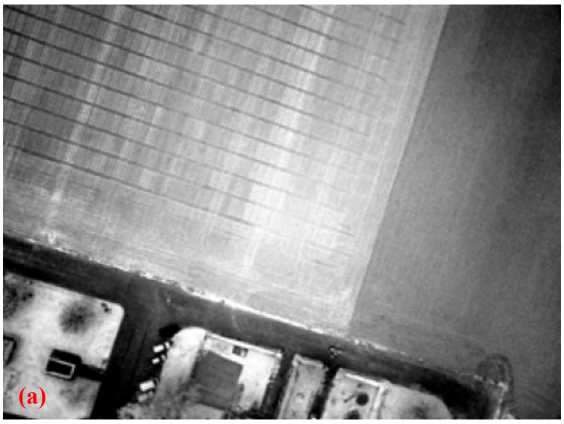
First, a mean of an image series acquired with the same camera tunings is made. From the image mean, we calculate its radiometric profile. Secondly, we extract the coefficients of a fitted multiplicative polynomial. This polynomial is minimum a quadratic. Then, this polynomial function is applied to each image in order to obtain a corrected image (Figure 9).

3.4 Linear conversion of digital images

The actual output voltage from each cell of an image sensor in a digital camera is proportional to the number of photons that hit the cell during the exposure. This was confirned by Cescatti (2007) who experienced a perfect linearity between the signal (DC divided by the shutter speed) and the raw signal of a LAI-2000 quantum sensor.

4. GEOMETRIC CORRECTIONS

For each camera, the lens distortion was measured using POIVILLIERS ‘E’ developed by Yves Egels (IGN-ENSG, Paris, France). Then a standard commercial photogrammetric software was used in order to produce orthorectified imagery for each band.



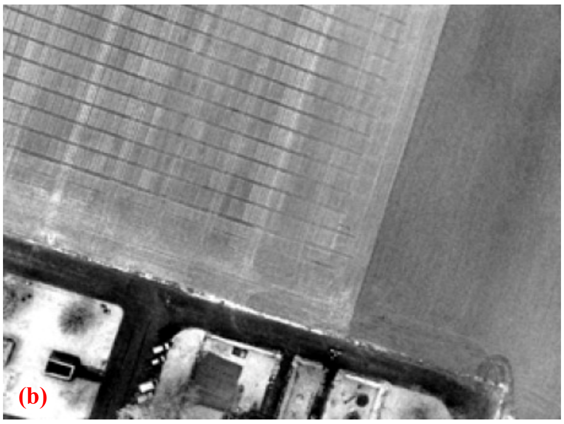


Figure 9. Near Infrared image before (a) and after (b) vignetting correction.

5. RESULTS

Figures 10a to 10d show radiometric and geometric corrected images acquired over sugarcane fields using the four cameras (visible, red edge, near infrared and thermal infrared). Parcel boundaries are overlaid.

Using the visible and near infrared images, an image of the Normalized Difference Vegetation Index (NDVI; Rouse et al, 1974) was calculated using the formula:

$$NDVI = (NIR-Red) / (NIR + Red) \quad (3)$$

where NIR and Red are respectively the Digital Counts in the Red and Near Infrared images.

On field measurement on these parcels shows good relationships between cane biomass and NDVI image and also between thermal infrared measurement and hydric stress (Lebourgeois et al., 2007). Current research works are conducted in order to better assess these relationships so that these products could be used directly for precision farming.

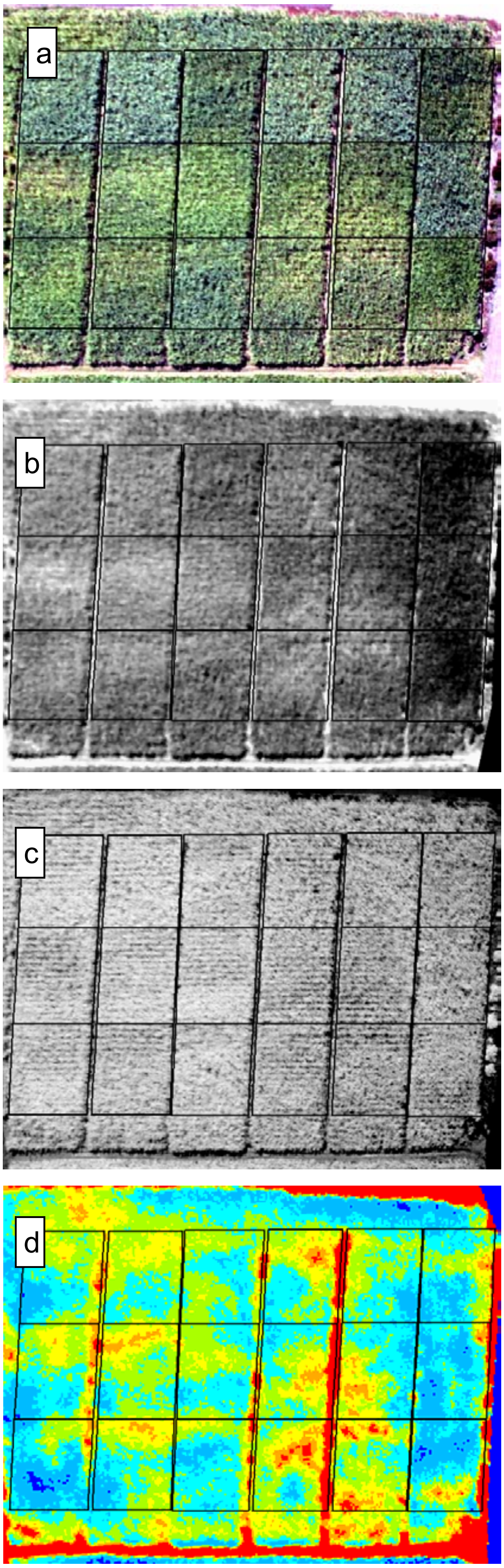


Figure 10. Geometric and radiometric corrected images in (a) RGB bands (Canon ® EOS 350 D), (b) Near Infrared band (modified Canon ® EOS 350 D), (c) Red Edge band (modified Canon ® EOS 350 D). and (d) Thermal infrared band (FLIR ® B20 HS).

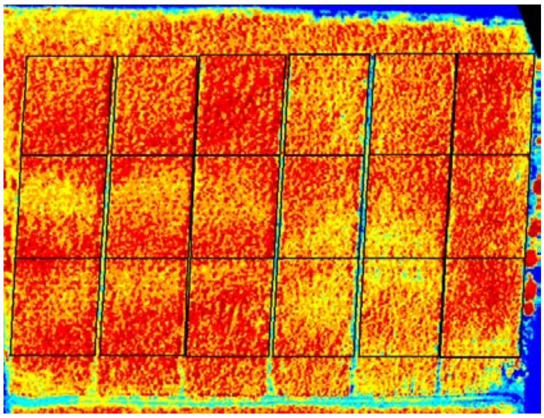


Figure 11. Example of an NDVI image produced with the Red band of the RGB image (Figure 10a) and the Near Infrared band (Figure 10b).

5. CONCLUSION

Ultralight aircraft and UAV in combination with small digital cameras permit to acquire low cost high resolution images particularly useful for applications with a high turn-over, like agriculture.

In this paper, through examples based on Canon cameras mounted on an Ultra Light aircraft, we tried to list and present a set of radiometric corrections (splitting spectral bands, correction of the vignetting effect in the near-infrared and red-edge bands, spectral characterization of the bands) that need to be applied to the images prior a quantitative use of the data.

The next step will be to compensate the radiometric changes due to atmospheric and illumination conditions in an image time series.

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