Small Format Optical Sensors for Measuring Vegetation Indices in Remote Sensing Applications: A Comparative Approach

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***Abstract*—In this paper we report the comparative study of two types of digital cameras to be used for vegetation index measurement. Using either a dedicated multispectral JAI AD-80-GE camera or a custom dual Canon S3IS camera system, we obtained RGB and NIR images and processed them to obtain vegetation indices (NDVI, EVI and two-band EVI). Since no radiometric calibration is available for both systems, normalized reflectance images are not available and we have to determine relative gain factors for the various bands in order to get likely vegetation indices. Moreover, the two camera system requires image registration. Experimental results are provided.**

***Index Terms*—vegetation indices, multispectral camera, remote sensing.**

I. Introduction

Research in multispectral remote sensing using optical sensors for agriculture [1] has proven to get the characteristics of plants that influence reflectance and emission of electromagnetic energy. Reflectance differences between the plant leaves over the 0.5-1.4 micron range are caused principally by Fresnel reflections at external and internal leaf surfaces and by plant pigment absorption [2]. Measurements with a spectrophotometer made on the leaves showed that the largest increase in reflectance, about 5%, and decrease in transmittance, about 8%, occurred between average values for after-tagging-ages of cotton leaf over the 0.75-1.35-micron wavelength interval [3].

Broad-band red/near-infrared vegetation indices such as Leaf Area Index (LAI) and Normalized Difference Vegetation Index (NDVI) are measures of chlorophyll abundance and energy absorption which influence plant growth through photosynthesis [4]–[6].

Whereas most acquisition systems are embedded in satellites, some researchers also made measurements of LAI and NDVI using airborne systems. By using airborne multispectral images, Boegh et al. [7], [8] found that nitrogen concentrations (mass basis) are linearly related to spectral reflectance in the green and far-red spectral bands. Furthermore the development of the mosaicking technique using Unmanned Aerial Vehicle (UAV) [9] will provide an option in the development of low altitude and high resolution vegetation index mapping.

Our research focuses on studying the use of optical sensors to measure the vegetation indices and which are to be placed in UAV systems. We aim at providing images of vegetation indices in rather high spatial resolution (comparing to satellite sensors) for optical remote sensing. Our acquisition system has to be compact and lightweight enough to be portable. In this paper we are presenting and comparing two solutions. The first one uses two standard compact digital cameras, the Canon S3-IS. We modify one of them adding an internal filter in order to obtain the NIR information. The second solution consists in using a single dedicated multispectral camera, manufactured by JAI company.

II. Theoretical approach

A. Calculation of Vegetation Indices

Several metrics can be considered for studying vegetation. Among them, the most popular ones are:

$$NDVI = \frac{NIR - R}{NIR + R} \tag{1}$$

$$EVI = G\frac{NIR - R}{NIR + C_1 R - C_2 B + L} \tag{2}$$

$$EVI2 = G\frac{NIR - R}{NIR + (C_1 - C_2/c)R + L} \tag{3}$$

EVI stands for enhanced vegetation index and $EVI2$ stands for two bands enhanced vegetation index without blue band, and where NIR, R and B represent normalized surface reflectances averaged over ranges of wavelengths in the near-infrared ($\lambda \sim 0.8\mu m$), visible red ($\lambda \sim 0.6\mu m$) and visible blue ($\lambda \sim 0.4\mu m$) regions of spectrum, respectively. G is a gain factor, C_1 and C_2 are coefficients of the aerosol resistance term, $c = R/B$, and L is the soil adjustment factor. In MODIS EVI algorithm, $L = 1$, $C_1 = 6$, $C_2 = 7.5$, and $G = 2.5$ [10], [11].

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B. Spatial Resolution

There are reports of producing a 1 km spatial resolution land cover classification using data from the Advanced Very High Resolution Radiometer (AVHRR). The methodology was derived from a similar effort to create a product at 8 km spatial resolution, where high resolution data sets were interpreted in order to derive a coarse-resolution training data set [12]. Some researches also compare some different types of small format multispectral sensors, ones are commercially available systems, and the others are custom built systems [13], [14]. In this study we focus on the use of cameras to be placed on UAV, so we chose JAI AD-80-GE as a dedicated multispectral camera, and a custom built system made of two Canon S3IS cameras. The selection of these two types of cameras is related to their weight and dimensions that allow them to be placed in the fuselage of the UAV. With our final device we aim at producing images at less than 1 meter spatial resolution.

III. The Sensors and Used Methods

A. Dedicated Multispectral Camera

The JAI AD-080-GE is a multispectral camera that allows the combined use of visible and near-infrared light inside one camera. The 2-CCD system allows the simultaneous imaging via two channels and one objective lens. A CCD sensor with Bayer Mosaic color filter is used to filter the visible light, and a monochrome CCD sensor is used for NIR-light. The light beams of both spectrums are separated using a special dichroic prism and sensed by the corresponding sensors. The spectrum responses of the two sensors in the camera are shown on Fig. 1. Using a single lens system, this camera produces two precise geometric images which do not need to be registered.

B. Multispectral System using two Modified Cameras

For having visible and near-infrared light from common digital camera, we use two Canon S3-IS digital cameras. The first camera is used for acquiring visible light and the second camera for acquiring near-infrared light. These two cameras use 1/2.5” CCD sensor, providing 2816 x 2112 resolution images. The camera type selection is based on the consideration of the quality of images output and the weight / dimensions for utilizing camera in the airborne system, or unmanned aerial vehicle. Unfortunately we do not have the spectrum response of the Canon camera to our disposal. Modification for spectrum sensitivity has been made for the second camera by replacing visible light filter lens with infra-red filter lens inside the camera. We use an IR-72 compatible filter lens as the infra-red filter lens. With this filter, the second camera becomes sensitive to infra-red spectrum. As shown in Fig. 2, we also have made modification for operating the two cameras with the remote control aeromodeling system (radio controlled). Due to spatial lag between two images produced by the cameras, the corresponding images have to be registered before they get in the vegetation index formulas. And we use piecewise linear mapping function for registering the two images [15].

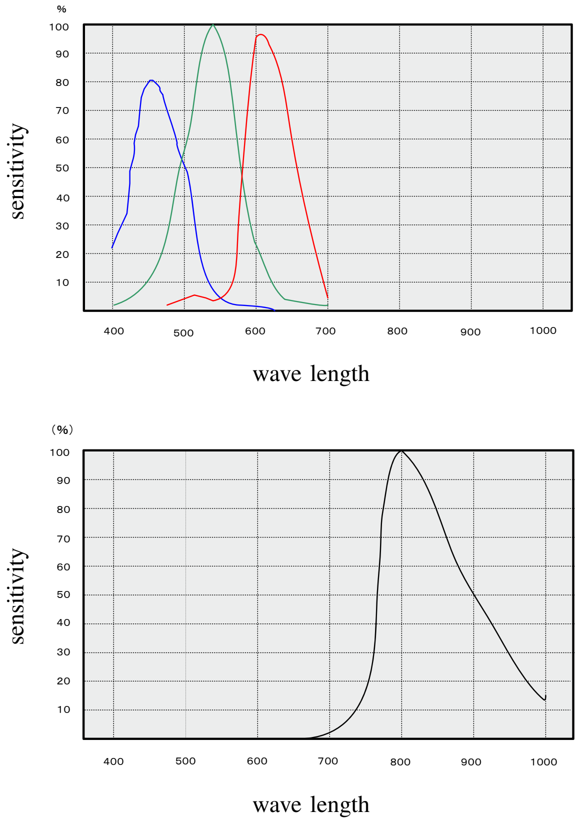

Fig. 1. Spectrum response for the two sensors in JAI AD-080 GE camera. On the top, sensitivity for RGB sensor, on the bottom for the IR one.

Fig. 2. The two Canon cameras and their controller.

IV. Comparison Methods

To compare the two acquisition systems, we first take some images and avoid saturation on the red, green blue and near-infrared bands as shown in flowchart in Fig. 3. Due to mounting structures and shutter controller of the two systems are not the same, the scenes and the snapshot time of the images and are not exactly the same. Then we compare the NDVI, EVI and EVI2 images. We set the aperture and shutter speed on the camera to adjust the saturation effect on the

TABLE I
CHARACTERISTICS OF THE TWO SYSTEMS

Parameters	**JAI AD-80-GE**	**Modified Canon S3-IS**
System base	2 CCD sensors (visible and NIR), single lens	2 cameras with two identic CCD sensors, one lens per camera
Resolution (max)	1024 × 768 pixels	2816 × 2112 pixels
Operating system	PC shutter	Microcontroller board shutter
Power supply	12 volt DC	4 × AA batteries
Weight	320 g + 60 g (lens)	2 × 410 g
Memory storage	PC by Gige interface	SD Card Memory

TABLE II
SETTINGS OF THE TWO SYSTEMS FOR OUR EXPERIMENTS

Settings	**JAI AD-80-GE**	**Modified Canon S3-IS**
Resolution	1024 × 768 pixels	2816 × 2112 pixels
Shutter speed	1/250 s for RGB 1/60 for NIR	1/1250 s
Focal length	8 mm	6 mm
Aperture	f/16	f/8

captured images: for Canon system we set exposure time manually, and for JAI system we did it automatically with a script to avoid the saturation and get the best shutter speed. These images were acquired in the city of Mulhouse, France, in the spring season on a sunny day. The characteristics of the two systems are shown in Table I, we set some parameters as shown in Table II.

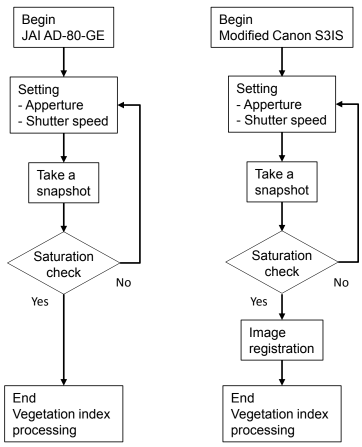

Fig. 3. Image capturing flowchart for the two systems.

V. RESULTS

We successfully obtained RGB and NIR images with both types of systems (Fig. 4 and Fig. 5). NIR images from the modified NIR Canon camera is taken from red band of RGB sensor.

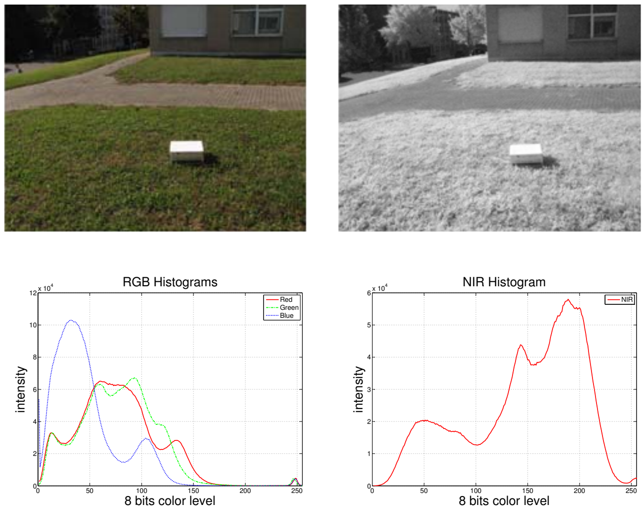

Fig. 4. Visible and near-infrared raw images from modified Canon S3IS.

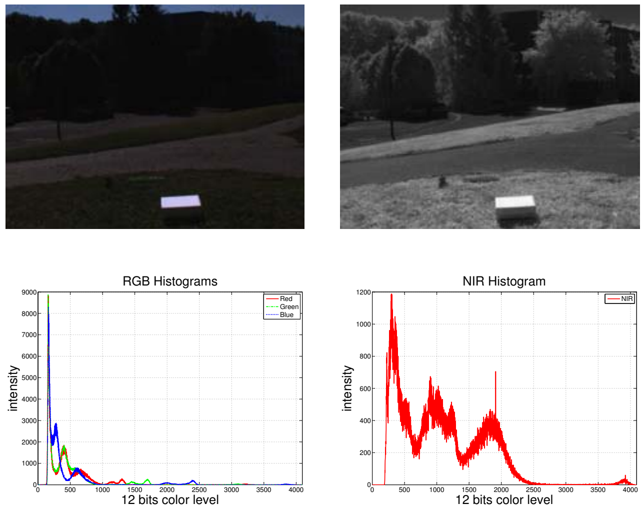

Fig. 5. Visible and near-infrared raw images from JAI AD-80-GE.

Nevertheless, computation of the various vegetation indices mentioned in Sec. 2 must be done carefully. Actually, the images we acquire are not normalized reflectance images, as requested. Moreover, since our sensors have no radiometric calibration, computing the indices with non-normalized images would lead to obvious errors.

In the NDVI computed with images provided by the JAI camera on Fig. 7, contrast seems inverted: grass appears dark and pavement appears bright. The solution is to evaluate the gain factors between each spectral band and to use modified criteria:

$$NDVI = \frac{k_{NIR}NIR - R}{k_{NIR}NIR + R} \tag{4}$$

$$EVI = G\frac{k_{NIR}NIR - R}{k_{NIR}NIR + C_1 R - C_2 k_B B + L} \tag{5}$$

$$EVI2 = G\frac{k_{NIR}NIR - R}{k_{NIR}NIR + (C_1 - C_2/c)R + L} \quad (6)$$

In our experiments, in order to get low cost reflectance reference, as [16] use white ceramic tile for reflectance standard instead of using spectralon, we use white paper as our reflectance reference to acquire reflectance factor for red, NIR and blue bands in both systems (JAI sensors and Canon sensors). Then we compute the coefficients k_{NIR} for NIR band and k_B for blue band for each system. With such calibration, vegetation index images are correct.

In Fig. 8 and Fig. 9 are shown the indices computed from the raw images of the scenes presented Fig. 4 and Fig. 5, after we have performed the registration of the Canon images and have performed the calibration in both cases. In the scene, we have grass, some different types of trees, buildings and pavement. We also can notice a box covered with white paper on its top: it is our reflectance reference. The greener the vegetation in the scene, the brighter it appears in vegetation index images.

Since the Canon system provides 8-bit images, parts of the indice images can be very noisy. In order to illustrate it, we present an acquisition of another scene Fig. 10. We have images of the same scene taken with our two systems. As we can see Fig. 10(b) in the region with low light (shadow at the bottom of the building) vegetation index appears very noisy. With the 12-bit JAI camera, this is not the case Fig. 10(d).

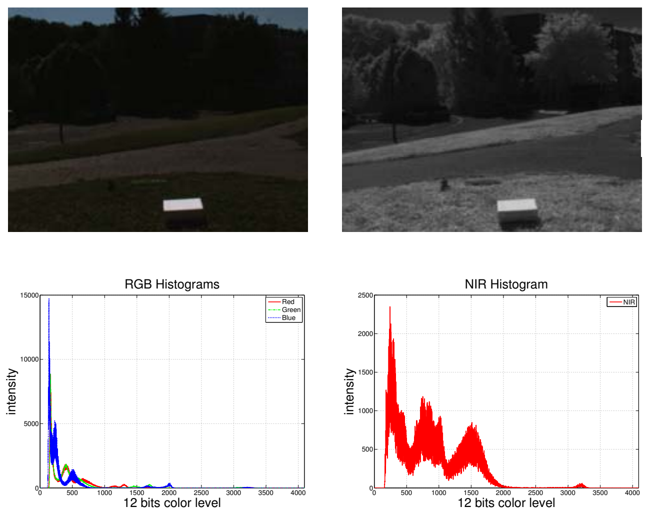

Fig. 6. Visible and near-infrared images from JAI AD-80-GE after calibration.

VI. Conclusion

We successfully implemented the production of vegetation index images using two architectures. A custom system made of two end-user cameras was shown to produce high-resolution images. Such a relatively inexpensive system, currently using 8-bit sensors, produces noisy images, and these images need to be registered. An alternative may consist in using a multi-spectral RGB/NIR camera such as JAI AD-80-GE. It produces

(a)

(b)

Fig. 7. Illustration of the calibration benefits. (a) result obtained by computing NDVI with the raw images presented Fig. 5. (b) result obtained after calibration with the calibrated images presented Fig. 6

moderate resolution images, but these latter prove high quality with their 12-bit depth.

In the growing of aerial imaging applications using airborne systems and unmanned aerial vehicle, it will be very good if camera manufacturers can provide multispectral cameras with portable features such as control systems, power supply and memory storage.

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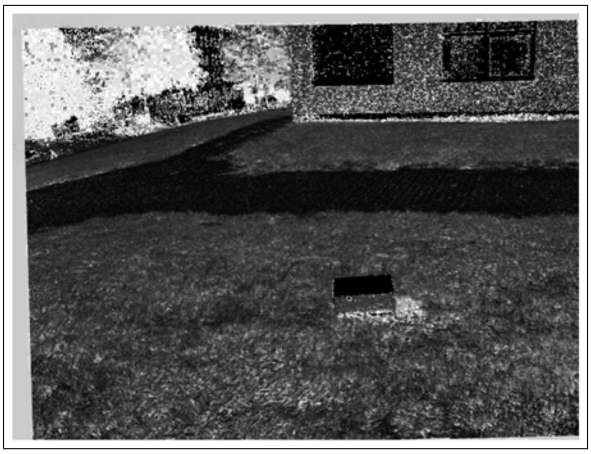
(a) NDVI



(b) EVI

(c) EVI2

Fig. 8. Computation of vegetation indices with images from the Canon 3SIS system. Indices images are not rectangular because of the registration we performed on RGB and IR images.

(a) NDVI

(b) EVI

(c) EVI2

Fig. 9. Computation of vegetation indices with images from the JAI AD-80-GE.

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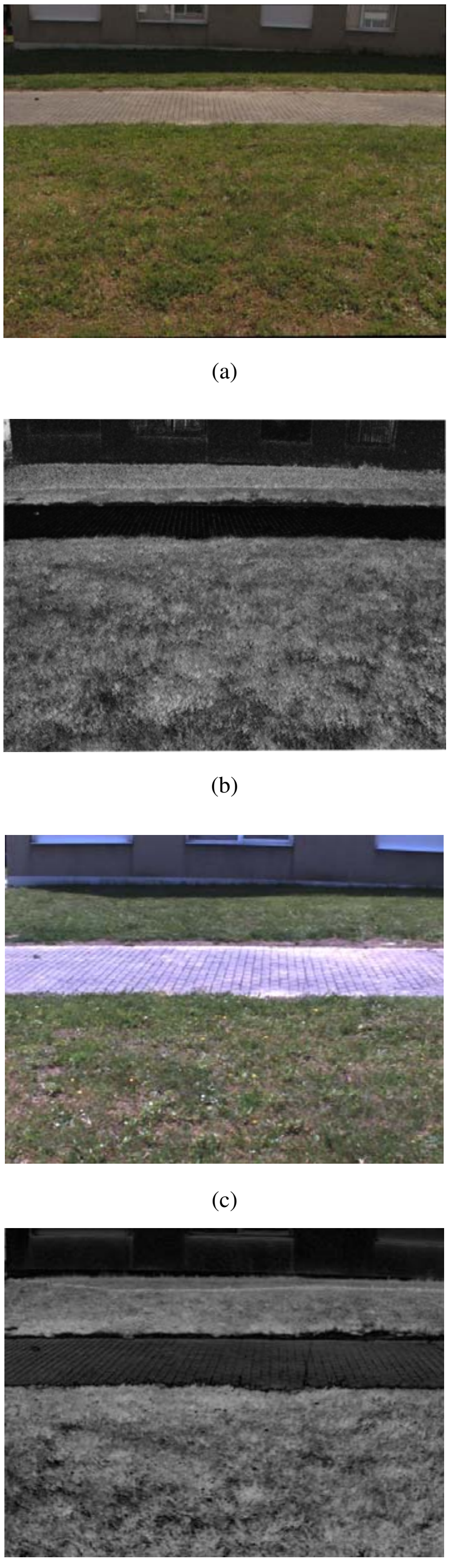

(a) (b) (c) (d)

Fig. 10. NDVI comparison of the same scene acquired.(a) RGB scene acquired with the Canon 3SIS system and (b) the corresponding computed NDVI. (c) RGB scene acquired with the JAI AD-80-80 and (d) the corresponding computed NDVI.