Digital Metric Camera radiometric and colorimetric calibration with simultaneous CASI imagery to a CIE Standard Observer based colour space

Lucas Martínez, Roman Arbiol, Vicenç Palà, Fernando Pérez

Àrea de teledetecció i procés d'imatge

Institut Cartogràfic de Catalunya (ICC)

Parc de Montjuïc s/n, 08038

Barcelona, Spain

Lucas.Martinez@icc.cat

Abstract—**The Institut Cartogràfic de Catalunya (ICC) operates a Digital Metric Camera (DMC), manufactured by Z/Imaging. It supports the simultaneous capture of panchromatic, RGB colour and near-infrared images. One of the most important ICC products is the Catalonia orthophotomap series. This product is intended to depict the territory as realistically as possible. With this aim, ICC is developing a project to obtain genuine colours in the photographic products produced with the DMC camera and this paper contains some preliminary results. Since an absolute radiometric calibration of the DMC is not available yet, this is accomplished through simultaneous images acquired with both DMC and a Compact Airborne Spectral Imager (CASI) also operated by ICC. These images are used to locate common areas imaged in similar geometrical conditions, and then a linear relationship between Digital Numbers (DN) from DMC and radiance values of a CASI image emulating DMC bands is calculated. To improve the colour of the DMC products, a colorimetric calibration based on polynomial transformations has been developed. This transformation allows changing from DMC-RGB space to a sRGB space that is based on CIE-XYZ colour space. Airborne ICC-CASI images acquired with a Cessna Caravan B20 over Banyoles (Spain) in 2005 were used to test the methodology. The comparison between the training colours and the ones obtained after colorimetric calibration yield differences in 8bit DN that range from 4 to 36 DN with a mean value of 12 DN. The effect was also visually analyzed on different subsets of images that include agriculture areas, urban landscape and a natural water layer. Finally, it was found that the application of both calibrations to the DMC images results in a consistent colour combinations for all the analyzed subsets.**

Keywords- *DMC, CASI, radiometric calibration, colorimetric calibration, sRGB.*

I. INTRODUCTION

In 2004 the Institut Cartogràfic de Catalunya (ICC) acquired its first digital Z/I Digital Metric Camera (DMC). The DMC camera simultaneously captures a high resolution panchromatic image of 13,824 x 7,680 pixels and four multi-spectral images (red, green, blue and near infrared) of 3,072 x 2,048 pixels. The high resolution image is formed from the images acquired with four inclined panchromatic high resolution camera heads with a focal length of 120 mm. The lower resolution multi-spectral images in the colour bands red, green, blue and near-infrared are acquired by four additional nadir looking camera heads with a focal length of 25mm. The DMC Field of View (FoV) or swath angle is 69.3° across strip and 42° along strip [1, 3].

Despite the high radiometric performance of the camera, the Z/I DMC calibration report does not allow to obtain absolutely calibrated physical measurements in radiance units. Besides, the colours of the multi-spectral images do not match the real colours due to the different sensitivity of the DMC versus the Human Visual System (HVS) [4].

The ICC has started a project to obtain realistic colours in the photographic products produced with the DMC camera, based on physical models and hypothesis that improve empirical radiometric normalizations of the images. The project is structured as a two-step procedure:

- Spectral calibration of the DMC visible bands. This will allow inferring absolute radiometric values from DMC data.

- Colorimetric calibration to a CIE-based standard colour space. This will help to obtain more natural colours from DMC.

The ICC owns and operates Compact Airborne Spectrographic Imager (CASI) manufactured by Itres Inc. [5]. The ICC-CASI configuration is a CASI 550 system (Table I) synchronized with an Inertial Navigation System (INS) and a Differential Global Positioning System (DGPS). The integrated assembly is designed to convert the sensor imagery captured by the CASI into true ortho-images, useful for cartographic purposes [6].

The CASI system is periodically recalibrated at laboratory. Spectral calibration of the DMC can be obtained from images taken both with DMC and CASI simultaneously operating from the same aircraft.

TABLE I.   CASI 550 SPECIFICATIONS

CASI 550 Specifications	
Field of View	40.4° across-track 0.077° along track
Spectral Range	545nm between 400 and 1000nm
Spectral Samples	288 at 1.9nm intervals
Spectral Resolution	2.2 nm FWHM at 650
Aperture	F/2.8 to F/11.0
Dynamic Range	16,384:1 (14 bits)
Signal to Noise Ratio	790:1 peak
Calibration Accuracy	470 - 800 nm +/-2% absolute

The colorimetric description of a colour is not an easy mission. We see colours because objects reflect a fraction of the light that comes to them. So, colours depend on the object, the source of light and even the colour of the environment of the object. These facts are the field of study of the colorimetric science. The Commission Internationale de L'Eclairage (CIE) was created to standardize these issues [7, 8].

The trichromatic theory of colour vision is based on the premise that there are three classes of cone receptors involved in colour vision and dates back to the 18th century. One important empirical aspect of this theory is that it is possible to match all of the colours in the visible spectrum by an appropriate mixing of three primary colours. In 1931 the CIE proposed a basic space for the HVS known as CIE-XYZ [9] with positive colour matching functions (Figure 1). From this space it is possible to reach all the other colour spaces such as RGB, Lab, etc. by means of some simple algebra.
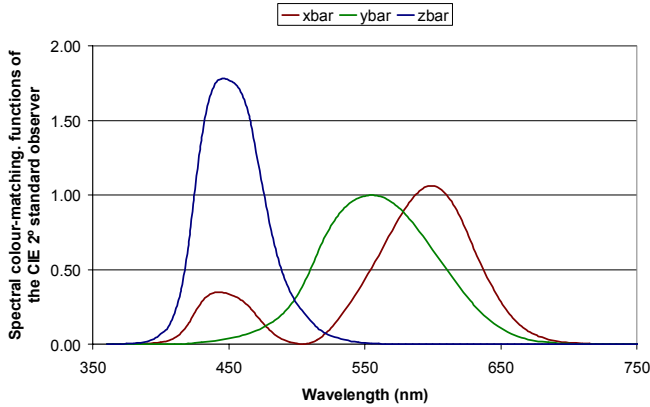

Figure 1.   Colour matching functions for 1931 CIE-XYZ 2° observer.

DMC output constitutes a particular RGB space. In order to transfer its colour space to a camera independent space as XYZ there are two main approximations. The first one is the integral method [10] and the second one is the mathematic method [11-13]. Both methodologies are fed by ancillary radiometric data. As this paper is just a demonstrator of the DMC colorimetric capabilities and for the shake of simplicity, only the mathematic method will be applied.

In the following sections we first make a description of the proposed algorithms. Then, we perform the radiometric and colorimetric calibrations using sample images obtained during a test flight over Banyoles (Spain). The results will be shown for several sub-scenes that include water layers, vegetated and crop regions and urban areas.

II. METHODOLOGY

A. DMC radiometric calibration

As an absolute radiometric calibration of the DMC is not available from the manufacurer, this relationship will be obtained from simultaneous images incoming from both DMC and CASI sensors. This is possible due to the fact that the acquisition geometry, atmospheric effects and illumination geometry of the targets are the approximately equivalent for areas imaged simultaneously. Besides, the spectral resolution of CASI is high enough to reproduce DMC-like channels by adding calibrated CASI hyper-spectral bands. In order to verify the previous hypothesis and because of the different FoV of DMC and CASI, only the central area of the DMC scene were used. Besides, DMC pixels were aggregated to fit the coarse CASI spatial resolution. Then a median floating window filter was applied to both CASI and DMC imagery to avoid misregistration and other sources of noise. Finally, a linear relationship between Digital Numbers (DN) from DMC and radiance values of a CASI image emulating DMC bands (Equation 1) is derived.

$$DMC_{DN(simulated\ from\ CASI)} = a + b \cdot DMC_{DN} \qquad (1)$$

B. DMC colorimetric calibration

The mathematic approximation of the colorimetric calibration involves finding a mathematical expression that allows the change from a given colour space to another one (Equation 2).

$$\begin{aligned} R_{eye} &= R_{eye}\left(R_{DMC}, G_{DMC}, B_{DMC}\right) \\ G_{eye} &= G_{eye}\left(R_{DMC}, G_{DMC}, B_{DMC}\right) \\ B_{eye} &= B_{eye}\left(R_{DMC}, G_{DMC}, B_{DMC}\right) \end{aligned} \qquad (2)$$

This expression is calculated from a set of training colour measurements or values obtained from those measurements. In this paper, the training colours proposed are the GretagMacbeth ColorChecker chart (Figure 2).

Figure 2.   Gretag Macbeth ColorChecker original chart

The ColorChecker chart consists of 24 colour patches chosen to represent common natural colours such as human skin colours, foliage, and sky, in addition to additive and subtractive primaries, and a six-step grey scale [14-15].

Spectral values for each patch are available [16]. These values have been used to compute DMC-RGB and sRGB values based on CIE-XYZ space. The sRGB colour space is proposed in this work because it is widely used nowadays, but any other RGB colour space is suitable for the proposed methodology.

These spectral data have been used to compute DMC-RGB and sRGB values based on CIE-XYZ space using the Equation 3 and a gamma of γ=2.2 [17].

$$\begin{bmatrix} R_{sRGB} \\ G_{sRGB} \\ B_{sRGB} \end{bmatrix} = \begin{bmatrix} 3.2410 & -1.537 & -0.498 \\ -0.969 & 1.8760 & 0.0416 \\ 0.0556 & -0.204 & 1.0570 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (3)$$

Finally the proposed mathematical relationship described in Equation 2 was selected as three polynomial expressions that describe Equation 3, one for each sRGB band.

The polynomial degree and mixed terms are the consequence of the differences between DMC spectral sensibility [4] and XYZ sensibility (Figure 1) that corresponds to the psychophysical sensibility of the HVS.

$$\begin{bmatrix} sR & sG & sB \end{bmatrix} = \begin{bmatrix} A \end{bmatrix}_{3x10} \begin{bmatrix} 1 \\ R_{DMC} \\ G_{DMC} \\ B_{DMC} \\ R_{DMC}G_{DMC} \\ R_{DMC}B_{DMC} \\ G_{DMC}B_{DMC} \\ R_{DMC}^2 \\ G_{DMC}^2 \\ B_{DMC}^2 \end{bmatrix} \quad (4)$$

III. DATA SET AND RESULTS

Airborne ICC-CASI and DMC images (Table II) were acquired on June 29th, 2005 with a Cessna Caravan B20, between 10-11 am. The area selected to be imaged was Banyoles (Spain). The CASI images were calibrated with laboratory coefficients to radiance units and orthorectified with DGPS and INS data, using a nearest neighbour procedure. The DMC image set was aero-triangulated and orthorectified with a nearest neighbour procedure.

TABLE II.   BANYOLES TEST FLIGT DATA DESCRIPTION

Flight	DMC image	DMC pixel	CASI image	CASI pixel	Altitude
Upper	80050110	0.4m	d240f09	6.0m	4,772m
Middle	80040045	0.2m	d240f04	3.0m	2,511m
Bottom	80020087	0.1m	d240f06	1.5m	1,369m

The images were pre-processed as described on the methodology section and afterwards a radiometric calibration was performed through a linear regression of equation 1 for each band and image. All the r^2 values obtained were greater than 0.9. Table III shows the radiometric calibration coefficients obtained for the images described in Table II.

TABLE III.   RADIOMETRIC CALIBRATION COEFICIENTS OF DMC RGB BANDS BY USING CASI CALIBRATED IMAGES SIMULATING DMC BANDS

	DMC Red band	DMC Green band	DMC Blue band
Upper flight	a = 295,5274 b = 8,783107	a = 831,3499 b = 5,267453	a = 573,9115 b = 8,052600
Middle flight	a = 355,6550 b = 7,806571	a = 435,5204 b = 5,005234	a = 880,9725 b = 7,020060
Bottom flight	a = 4171,445 b = 2,775348	a = 4099,081 b = 1,593823	a = 3899,278 b = 1,826133

Figure 3 shows the result of the application of the radiometric calibration on raw DMC RGB images to obtain DMC RGB reflectance values. Figure 3.b.1 has some building roofs on magenta shades. This is because the raw DMC green DN on those areas were over 90% of the range, where the sensor seems to lose linearity.

(a.1)   (a.2)
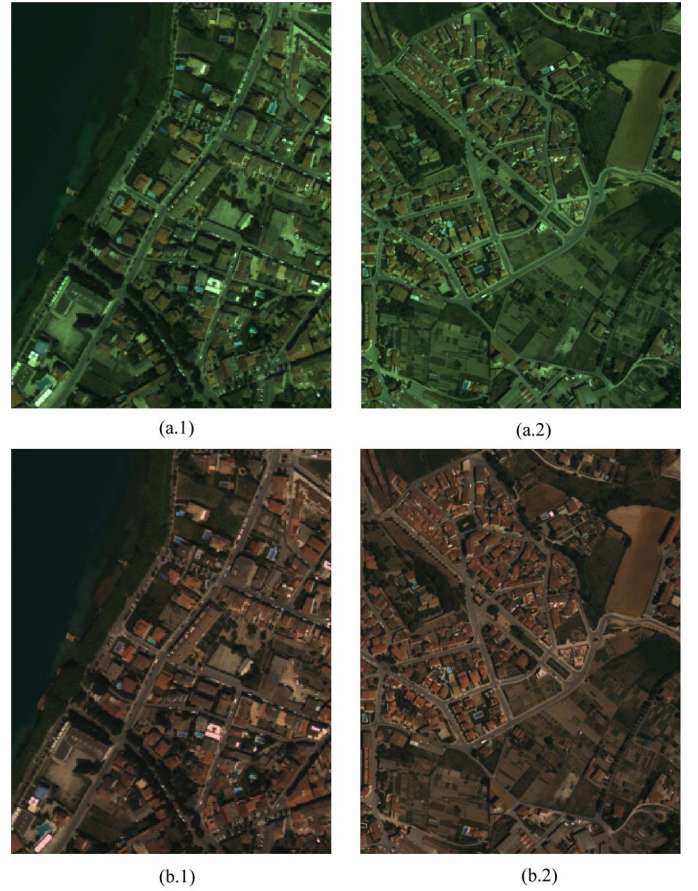
(b.1)   (b.2)

Figure 3.   Example of radiometric calibration of DMC RGB bands. Subscene a.1 and a.2 are raw DMC lower flight images. Subscene b.1 and b.2 are the a.1 and a.2 DMC images radiometricaly calibarted.

Then the colorimetric calibration was performed by a linear regression of Equation 4 for RGB bands. The data used to obtain the regression coefficients were obtained from the GretagMacbeth ColorChecker spectra.

A_{3x10}		
0.18 +/- 0.03	0.188 +/- 0.012	0.195 +/- 0.015
2.2 +/- 0.3	-0.67 +/- 0.14	0.28 +/- 0.16
-0.24 +/- 0.4	2.33 +/- 0.18	-1.1 +/- 0.2
-0.3 +/- 0.4	-0.17 +/- 0.16	2.4 +/- 0.2
1.8 +/- 0.8	-0.2 +/- 0.3	0.6 +/- 0.4
1.0 +/-1.9	-0.9 +/- 0.8	1.5 +/- 1.0
0.3 +/- 0.7	0.6 +/- 0.3	0.2 +/- 0.4
-2.4 +/- 0.5	0.5 +/- 0.2	-0.4 +/- 0.3
-0.7 +/- 0. 9	-1.3 +/- 0.4	-0.5 +/- 0.4
-0.8 +/- 1.5	0.7 +/- 0.6	-2.1 +/- 0.7

Table IV shows the results of the calculations done for the colorimetric calibration. As it can be observed the σ values are large, because of the few data used to do the linear regressions.

The comparison of the training colours with the ones obtained after colorimetric calibration yields differences in 8bit DN that range from 4 to 36 DN with a mean value of 12 DN.
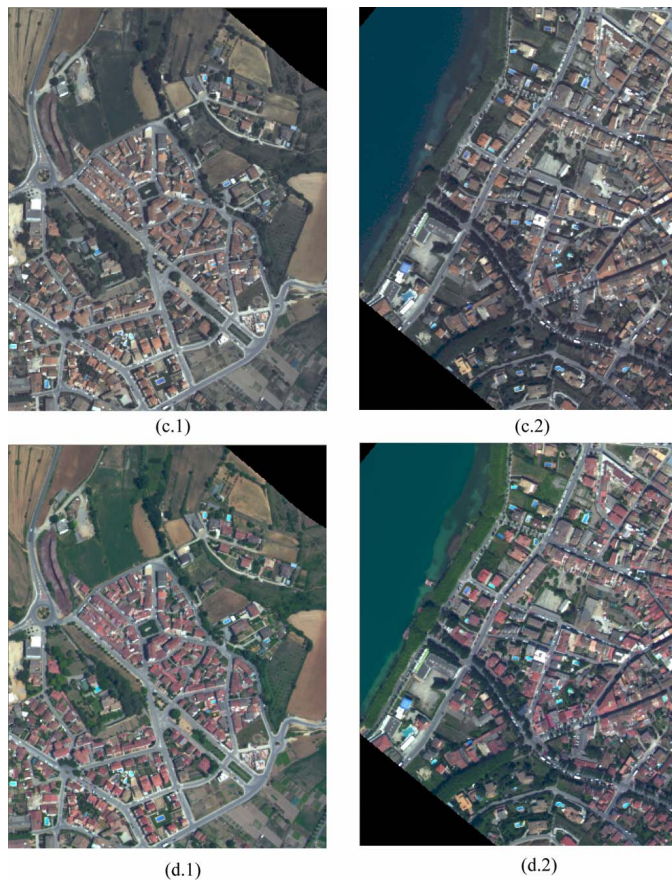

Figure 4.   Example of colorimetric calibration of DMC lower flight RGB bands. Subescene c.1 and c.2 are radiometricaly corrected DMC lower flight images. Subescene d.1 and d.2 are the c.1 and c.2 DMC images colorimetricaly calibarted. (Images normalized by the histograme values).

Figure 4 shows the result of the application of the colorimetric calibration on DMC RGB images after radiometric calibration. As the figure illustrates, the vegetation covers, crops, urban areas and water layers improve the hues to more natural ones.

CONCLUSIONS

In this paper a methodology for absolute radiometric calibration for DMC camera by using simultaneous CASI imagery has been proposed. Besides, a mathematical colorimetric calibration has been proposed and calculated by means of the ColorChecker spectrums. The radiometric calibration was successfully computed and the colorimetric calibration yield differences in 8bit DN ranging from 4 to 36 DN and a mean difference of 12 DN for the training colours. Finally, it was found that the application of both calibrations to DMC imagery results in correct colour combinations for all the analyzed subsets. These results indicate that DMC cameras are suitable to be used as a calibrated sensor and that DMC is able to produce imagery with realistic colours.

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