ABSOLUTE SPECTRORADIOMETRIC CALIBRATION OF THE ADS40 SENSOR

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ABSTRACT:

Digital cameras have spectral and radiometric properties superior to analogue film cameras. Due to its radiometrically stable construction the ADS40 sensor is capable of making images for cartography as well as remote sensing applications. For the increased size of current projects, for sensor fusion, as well as for change detection purposes it is necessary to produce comparable images for different flight conditions (weather, camera system, etc.). This is not possible with classical film cameras since comparable images require the absolute radiometric calibration of the imaging system, before atmospheric correction, reflectance calibration and BRDF correction can take place. The methods for satellite laboratory calibration can be also used for digital airborne cameras. A laboratory calibration of the ADS40 is made with a calibrated integrating sphere in order to determine dark signal, lens falloff, and radiometric gain for each sensor line. For the ADS40 a linear radiometric model is sufficiently accurate. The knowledge of the system spectral response allows a more accurate calculation of the radiometric calibration coefficients and is a check for system integrity. In order to provide a regional camera service, radiometric calibration facilities are being established on several service sites of the world.

RESUME:

Les caméras numériques ont des propriétés spectrales et radiométriques supérieures aux appareils à film. En raison de sa construction radiométrique stable le capteur ADS40 est capable de prendre des images pour la cartographie aussi bien que pour la télédétection. A cause de la grandeur augmentée des projets actuels, pour la fusion des donnés et pour la détection des changements il est indispensable de produire des images comparables pour les conditions de vol différentes (le temps, le système de caméra, etc.). Ce n’est pas possible avec les appareils à film parce que les images comparables exigent une calibration absolue du système à images avant que la correction d’atmosphère, la calibration de réflectance et la correction des effets de la BRDF peuvent survenir. Les méthodes de calibration de laboratoire des satellites peuvent être aussi utilisées pour les caméras numériques. Une calibration de laboratoire de l'ADS40 est effectuée avec une sphère intégrante calibrée pour déterminer le courant d’obscurité, l’assombrissement au bord de l’objectif et la sensibilité radiométrique pour chaque ligne de détecteur. Pour l'ADS40 un modèle radiométrique linéaire est suffisamment exact. La connaissance de la réponse spectrale du système permet un calcul plus exact des coefficients de calibration radiométrique et de plus, c’est un contrôle de l'intégrité du système. Pour proposer un service de caméra régional, l'équipement de calibration radiométrique est établi sur plusieurs sites de service au monde.

KURZFASSUNG:

Digitalkameras haben spektrale und radiometrische Eigenschaften, die jenen der analogen Filmkameras überlegen sind. Durch seine radiometrisch stabile Konstruktion kann das ADS40 Sensorsystem sowohl für kartographische als auch für Fernerkundungszwecke eingesetzt werden. Die Größe heutiger Befliegungsprojekte, die Fusion verschiedener Sensordaten, sowie die Zeitreihenanalyse erfordern vergleichbare Bilder bei verschiedenen Flugbedingungen (Wetter, Kamerasystem, etc.). Dies ist mit klassischen Filmkameras nicht möglich, da vergleichbare Bilder die absolute radiometrische Kalibrierung des Kamerasystems voraussetzen, bevor eine Atmosphärenkorrektur, eine Kalibrierung auf Reflexionsgrad und eine BRDF-Korrektur stattfinden können. Die Methoden der Laborkalibrierung von Satelliten kann auch auf digitale Luftbildsysteme übertragen werden. Eine Laborkalibrierung der ADS40 wird mittels einer kalibrierten Ulbrichtkugel durchgeführt, um den Dunkelstrom, Randabfall und radiometrische Verstärkung für jede Sensorzeile zu bestimmen. Dabei ist ein lineares radiometrisches Modell für die ADS40 hinreichend genau. Die Kenntnis der spektralen Responsekurve ermöglicht eine genauere Berechnung der radiometrischen Kalibrationsfaktoren und ist zugleich eine Überprüfung des optischen Systems. Um regionalen Sensorsupport anbieten zu können, werden radiometrische Kalibrationseinrichtungen an verschiedenen Standorten auf der Welt eingerichtet.

1. INTRODUCTION

Photogrammetric film cameras were originally developed for visual interpretation, so film development was optimised for the perceptive properties of the human eye. Since the geometric resolution of the eye can be enhanced by optics up to the wavelength of light, the film material is optimised for geometric resolution. The information content of aerial images, however, is not restricted to geometrical structures, but also consists of greyscale and colour values. The human eye can distinguish about 7 bit in greyscale and 3x7 bit in colour values which has set the limits for film development and digital scanners.

Modern digital sensors by far exceed this limit and will reach up to 12 bit true information depth. A high brightness dynamics and a resulting higher edge contrast can even compensate for lacking spatial resolution, as is suggested by the General Image Quality Equation (GIQE, Leachtenauer et al., 1997), which has been developed for military reconnaissance.

For many applications it is sufficient to measure a relative grey scale. This is called densitometry in classical photogrammetry. But already at this point film with its large exposure range and development uncertainties does not allow for producing comparable results for changing light situations. Therefore a calibration of classical film is only possible for a specific flight project. Furthermore, methods for atmospheric correction which are based on physical models require the knowledge of the absolute value of the light level. Finally, in remote sensing, absolute brightness and colour values are required for calculating physical variables.

Due to its radiometrically stable construction the ADS40 can be calibrated to physical brightness values and therefore be used in remote sensing applications. The radiometric data flow for ADS40 data is briefly described here (Beisl et al., 2006):

- As a first data product the ADS40 sensor provides raw (level 0) data which are corrected for Dark Signal Non-Uniformity (DSNU, i.e. dark current), and Photo Response Non-Uniformity (PRNU, i.e. lens falloff).

- The next step is the calibration for at-sensor radiance in level 1 data combined with a rectification of camera movements. An optional de-hazing with a modified Chavez algorithm is possible.

- For remote sensing purposes the spectral properties are designed such that spectrally non-overlapping bands comparable to Landsat bands 1-4 are available. The absolute calibration allows for an atmospheric correction based on physical models. Then a reflectance calibration can be performed to obtain ground reflectance. This is the basis for a proper correction of bidirectional effects from the target.

- In order to match the spectral sensitivity of the human eye a color transformation is possible during data processing.

Airborne sensors can be returned to the laboratory for recalibration which is not the case for satellites. So for satellites, a set of in-flight or vicarious calibration methods has been developed, which includes costly ground measurements by trained personnel. Fortunately, the operating conditions for airborne sensors are not as adverse as are those in satellites, so a regularly repeated laboratory calibration gives an easy and cheap way of assuring data quality.

2. RADIOMETRIC CALIBRATION FOR PHOTOGRAMMETRY AND REMOTE SENSING

2.1 Radiometric Quantities

2.2 Calibration Procedure for the ADS40

Radiometric Model

The simplest radiometric model that can be applied to CCD sensors in good approximation is a linear model. The grey values DN (digital numbers) depend on the calibration factor C_1 and an offset C_0. L denotes the band averaged spectral radiance.

$$L = C_1\, DN + C_0 \qquad (1)$$

For the ADS40 the offset C_0 is corrected already in the system correction during registration, so it can be set to 0.

Since the dependence on the integration time t is linear we can define a specific calibration coefficient c_1 as follows

$$c_1 \equiv C_1\, t \qquad (2)$$

$$L = \frac{c_1\, DN}{t} \qquad (3)$$

The specific calibration factor is a sensor constant with units [W s m^{-2} sr^{-1} μm^{-1} DN^{-1}] and is provided in the geometric calibration file of the ADS40.

System Correction for the ADS40

The system correction corrects for sensor artefacts and delivers data according to the sensor model. It is applied to the data before registration on the hard disk (Schuster and Braunecker, 2000).

Dark Signal Non-Uniformity (DSNU) correction: By their construction principle CCD lines will produce a signal even without any incoming light (Graham et al., 2004) which depends on temperature, integration time, and to a smaller extent from the pixel position. The temperature dependence is eliminated by a temperature controlled Peltier cooler which keeps the focal plate at 20° C. The integration time dependence is removed by a control loop which is fed by the signal of artificially darkened pixels at either end of the sensor line. The pixel dependence is eliminated by measuring and averaging the offset for each pixel. This value is saved for each pixel permanently in the sensor head and is subtracted from the signal.

Photo Response Non-Uniformity (PRNU) correction: The signal amplification varies for each pixel due to CCD manufacturing tolerances. More important, there is a lens falloff to the borders of the field of view. This gives a non-uniform response along the CCD line. Therefore a correction factor is calculated for each pixel from the ratio of the maximum value in the line to the actual pixel value. It is stored permanently in the sensor head and applied after the DSNU correction.

The PRNU corrected signal is therefore constant across the CCD line for a uniform illumination. The DSNU and PRNU corrected value is used for calculating the specific calibration factor c_l following equation (3).

Spectral Calibration

In order to calculate the amount of light that reaches the CCD line in the radiometric calibration measurement, the spectral response function R(λ) of the sensor has to be known.

The ADS40 is designed with four non-overlapping spectral channels in the blue, green, red, and near infrared (NIR) region together with panchromatic stereo channels. An optional near infrared channel in the so-called red edge of the vegetation spectrum is available in some configurations (
Table 1). The boundary wavelengths are given at the point of full width at have maximum (FWHM).

Band	Lower Wavelength FWHM [nm]	Upper Wavelength FWHM [nm]	Bandwith FWHM [nm]
Blue	430	490	60
Green	535	585	50
Red	610	660	50
NIR1 (Option)	705	755	50
NIR2	835	885	50
Panchromatic	465	680	215

Table 1. Spectral channels of the ADS40

The spectral sensitivity of the sensor is influenced by various parts in the sensor. First, there is a short wavelength cutoff at 400 nm originating from the lens. For the RGB colour bands the dichroitic beam splitter will cut out the different parts of the spectrum for each colour band. The final spectral shape is given by multilayer interference filters with sharp edges (cf. Figure 1). For the ADS40 the NIR and pan bands are shaped by interference filters, only. The overall response is given by the sensitivity of the silicon substrate of the CCD which has its maximum at 730 nm and falls off to half the value at 400 nm and 900 nm.

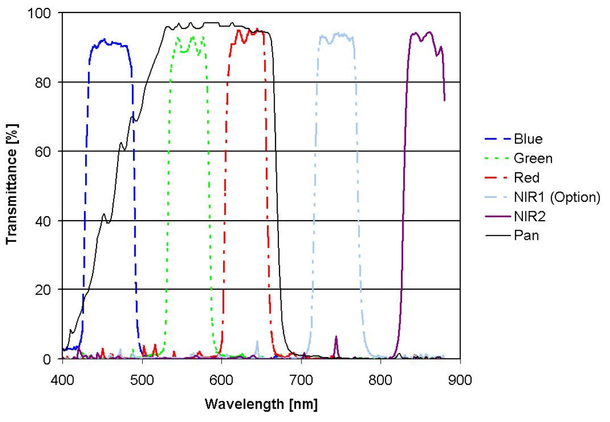

Figure 1. Spectral transmittance of the ADS40 colour filters

From this input data the spectral response function can be calculated. A laboratory facility for verification has been set up and first results can be seen in Figure 2.

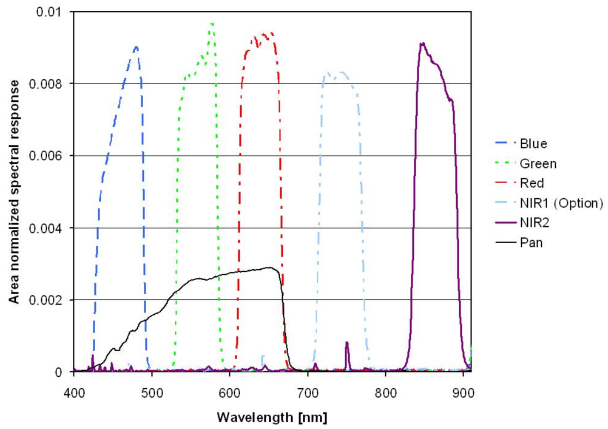

Figure 2. Spectral response normalized to unit area

Radiance calibration

With the spectral response curve of the camera R(λ) and the spectral radiance of the integrating sphere L(λ) the radiance of the integrating sphere that is emitted in each sensor band (band averaged radiance) can be calculated according to equation (4).

$$L = \frac{\int L(\lambda) R(\lambda) d\lambda}{\int R(\lambda) d\lambda} \qquad (4)$$

Equation 3 will then give the specific calibration factor c_l which is a sensor constant and is provided in the “RADIOMETRIC_GAIN” value in the geometric calibration file (*.cam) of the ADS40 sensor head. The c1 values are measured during camera production and are available from Leica on request. Though the camera is radiometrically stable a recalibration can ensure radiometric accuracy.

In order to keep the image data in a 16 bit unsigned integer data range (0-65535) the radiances are scaled during level 1 rectification in Leica’s GPro software by a factor of 50 to give calibrated digital numbers CDN. From GPro 3.x on, once the “RADIOMETRIC_GAIN” values are provided in the *.cam files, the CDN for each pixel are calculated from the original DN by

$$CDN = DN * 50\, c_1 / t \qquad (5)$$

So the processed image is calibrated to spectral at-sensor radiances although still unsigned integer values can be used. The band averaged spectral radiance L of the band is easily calculated by

$$L = CDN / 50 \qquad (6)$$

Linearity measurements

The linearity error of the CCD response is specified by the manufacturer to be below 5 %. To verify this, a set of apertures for the integrating sphere lamps has been built to create different light levels while leaving the spectral shape unchanged. Linearity measurements are in progress.

3. CALIBRATION FACILITIES AT LEICA GEOSYSTEMS

3.1 Spectral Measurement Unit

The Spectral Measurement Unit consists of a spectral light source and a goniometer (Figure 3, Figure 4). The spectral response is determined by measuring the CCD line response to the monochromatic light step by step for the whole spectrum.

In order to have a stable and continuous light source for the visible and near infrared spectrum a tungsten coiled filament lamp was chosen, which is operated with a regulated DC power supply. Low voltage small power lamps have small filaments with a high light density. Only a small illumination spot is necessary to illuminate the narrow CCD line.
A condensor system with order sorting filters and a diffuser is used for filling the monochromator aperture homogeneously. A large aperture monochromator will produce a bright monochromatic output which is collimated without chromatic aberration by an off-axis mirror collimator.

A NIST (National Institute of Standards and Technology, USA) traceable, calibrated UV enhanced silicon photodiode is used to make a relative calibration of the monochromatic beam. The ratio of sensor DN response to calibrated photodiode signal, normalized to one, is then the spectral response function.

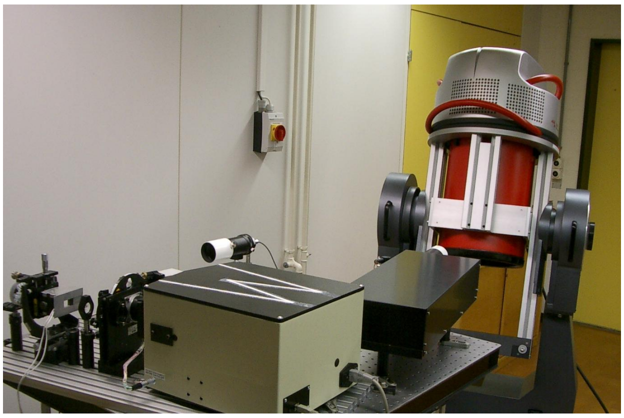

Figure 3. Spectral calibration and MTF measurement unit at Leica Geosystems

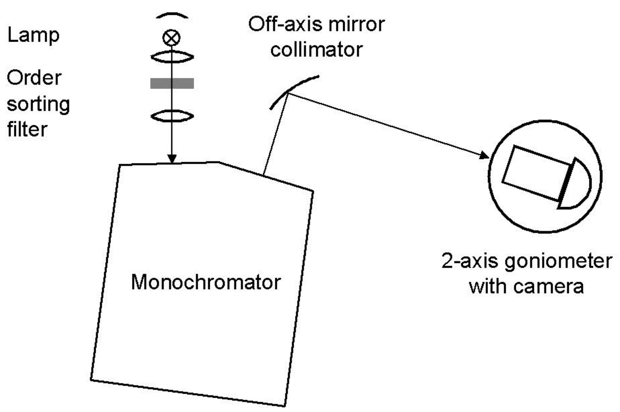

Figure 4. Spectral calibration unit (scheme)

3.2 Integrating Sphere

Whereas for spectral calibration only a small area of the CCD line has to be illuminated, the total line has to be illuminated homogeneously for the PRNU and radiance calibration. An integrating sphere with a diameter of 0.9 m is needed to fill the ADS40's FOV of ±32 degrees completely. A highly reflecting Bariumsulfate ($BaSO_4$) coating is producing a homogeneous illumination with deviations of less than 2% within the FOV (Figure 5).

As in the spectral calibration, tungsten lamps are chosen for broadband illumination from 400 nm to 900 nm. Three Satellite spheres, each with a lamp in it, are used as lambertian illuminators for the large sphere. Since the colour temperature of tungsten lamps cannot exceed 3400 K, the colour temperature of the sun of 5800 K cannot be reached this way. A conventional daylight conversion filter would require an input power that is a factor of 5 times higher. This would cause heat problems in the satellite spheres.

The use of Xenon lamps with daylight like colour temperature is problematic, since they are difficult to calibrate due to their sharp and unstable emission lines.

So we use blue power LED for enhancing the colour temperature. The emission line is in the middle of the ADS40 blue band and will cause no calibration issues. A stable power supply and a constant operating temperature of the LED is needed to have a constant light output.

A line spectroradiometer is used to transfer the radiance calibration from a NIST traceable, radiance calibrated sphere (Figure 6, Figure 7) to the large integrating sphere.

Figure 5. Integrating sphere for sensor calibration at Leica Geosystems

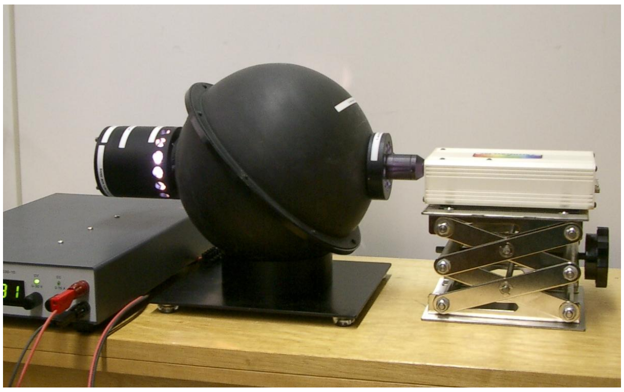

Figure 6. Calibrated radiance source and spectrometer

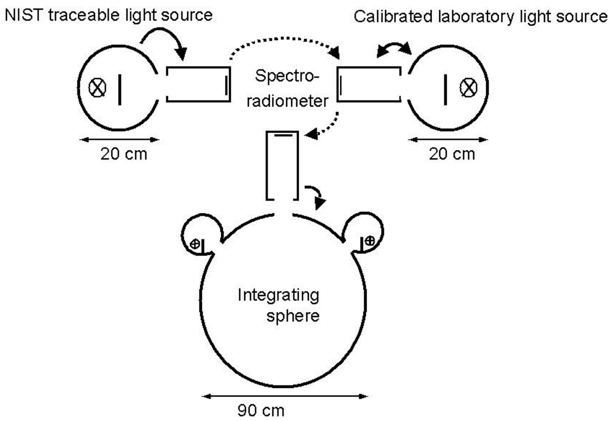

Figure 7. Transfer of the radiance standard

Figure 8 compares the radiance output of different sources: A bright target in direct sunlight, the large ADS40 calibration sphere and the calibrated laboratory sphere. The latter has an increased NIR output to compensate the lower sensitivity of the spectroradiometer in this spectral range.

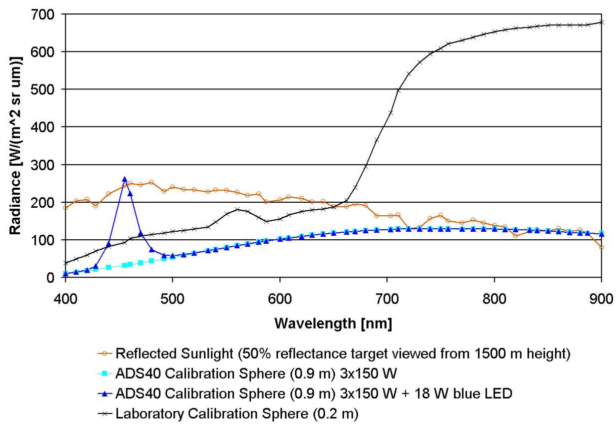

Figure 8. Comparison of the radiances of the ADS40 calibration sphere, and the calibrated laboratory standard with a simulated, solar illuminated 50 % reference target seen from the air at 1500 m height over ground

4. SUMMARY

In addition to the geometric information the radiometric information plays a growing role in imaging data. Airborne digital sensors are now capable of providing high quality radiance information. Therefore laboratory calibration facilities have been built to ensure the radiometric accuracy of the ADS40. For regional customer support radiometric calibration units are being installed at several service points in the world.

From GPro 3.0 onwards, the radiometric calibration factors are used to calculate standardized images for photogrammetry. For remote sensing applications radiance calibrated images can easily be calculated, which are the basis for further data products like ground reflectance images (Beisl and Woodhouse, 2004, Beisl et al., 2006).

5. REFERENCES

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