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To cite this article: F J Zheng et al 2014 IOP Conf. Ser.: Earth Environ. Sci. 17 012194

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In-flight Radiometric Calibration of Digital Photogrammetric Camera using Multi-grayscale Artificial Targets

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Abstract. With features of digitalization, light weight, high spatial resolution, high detection precision, production of digital photogrammetry sensors are widely used in aviation remote sensing replacing the analog sensors. One of the most attractive features of digital cameras compared with analog cameras is the radiometric properties. To implement spectral and radiometric calibration for digital photogrammetric cameras, a set of artificial targets were built in a test field. The artificial targets reflectance annual attenuation was measured, the result demonstrated that attenuation is influenced by gray scale changes. In this paper, in-flight radiometric calibration of SWDC was carried out in reflectance-based vicarious calibration method in 2011. The linear correlation between the sensor response and targets reflectance is 90% above. The apparent radiance that is simulated by radiation transfer is compared with the radiance value that is retrieved with calibrated coefficients, the relative difference is superior to 8% and it is sensitive to GSD.

1. Introduction

With the development of the CCD detector technology, the production of digital photogrammetry sensors with features of digitalization, light weight, high spatial resolution, high detection precision are widely used in aviation remote sensing replacing the analog sensors. One of the most attractive features of digital cameras compared with analog cameras is the radiometric properties. These properties create new prospects for the use of aerial images in remote sensing applications. Thereby, radiometric calibration of digital photogrammetric cameras should be carefully studied in order to improve quantitative application level.

Calibration is defined as a process of quantitatively defining the systems' responses to known controlled signal inputs. Absolute calibration is performed by determining the relation of the DN output (digital number, DN) from a sensor with the value of an accurately known, uniform radiance field at its entrance pupil. Currently, on-orbit absolute radiation calibration method has been widely used in the satellite calibration, but the traditional radiation test field does not apply to high spatial resolution photogrammetric sensors. Thereby calibration based on artificial targets is becoming a new issue in the case of photogrammetric sensor. Xv and Gou developed in-flight absolute radiometric calibration for hyper-spectral cameras based on artificial tarps. The objective of this article is to develop a method based on permanent artificial targets with nominal reflectance for test field calibration of radiometry for airborne instruments, subsequently measurement and analysis of targets.
optical characteristics and an empirical quantitative test of SWDC airborne sensor have been represented.

2. Theory and Method
The at-sensor radiance has many components, irradiance at the object is composed of direct sunlight, the skylight, the multiple scattering, and the light reflected from adjacent objects. Atmospheric influences are mainly caused by gaseous absorption and Mie and Rayleigh scattering processes and also dependent on the observation geometry. In the case of assumed plane parallel atmospheric conditions, at-sensor radiance is:

\[
L = L_a + \frac{E_s \mu_s T(\theta_s)T(\theta_v)}{1 - S \rho} \rho
\]

(1)

Where, \(L_a\) is path radiance, \(E_s\) is solar flux at the top of the atmosphere, \(\mu_s\) is cosine of sun zenith angle \(\theta_s\), \(T(\theta_s)\) is downward transmittance, \(T(\theta_v)\) upward transmittance, \(\theta_v\) is view zenith angle, \(\rho\) is equivalent reflectance, \(S\) is spherical albedo. Considering the influence of the dark current and noise, absolute calibration parameters are calculated using an appropriate model of linear sensors, such as CCD sensors, is the linear model (Equation 2). It is feasible to use averaged value of radiance and image measurements transforming the digital numbers to radiances for reflectance targets. The used calibration formula is:

\[
DC_i = A_i \cdot L_i + B_i
\]

(2)

Where, \(i\) represents the band of images, \(DC\) represents the image grey value, \(L_i\) represents the entrance pupil radiance of cameras \(W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}\), \(A_i\) represents the gain \(DC / W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}\), \(B_i\) represents the offset.

For airborne sensors, a feasible vicarious calibration approach is reflectance-based method \cite{12}. A procedure for the photogrammetric sensor calibration is shown in figure 1.

3. In-situ measurement and analysis of targets optical characteristics

3.1. Reflectivity measurement and analysis
Accurate referenced reflectivity targets are the precondition of radiation calibration. The average reflectance is calculated using the formula below:

\[
\bar{\rho} = \frac{R}{\bar{P}} \times B(\theta, \lambda)
\]

(3)
\( \bar{p} \) is the average reflectance of targets, \( \bar{R} \) is the target average response value which is measured by spectrometers, \( \bar{P} \) is the average response value of reference boards (whiteboard) with multiple measurements, and \( B(\theta, \lambda) \) is the reflection coefficient of calibrated reference boards. The artificial targets designed as reference targets, which are divided into two types: Large rectangular reflectance targets are composed of gray, red, black and white, and gray scale targets are composed of eight objects having different nominal reflectance of grey changes from black to white. The reflectance measured at nadir in October 2010 and October 2011 was shown in figure 2 and 3. The study showed that the average annual attenuation for the two types of targets is 18% and 10% respectively. The attenuation is inversely proportional to gray changes (color from deep to shallow), and the attenuation of white target is the largest, the stability of black targets is the best. Limitations of the reflectance reference targets were taken into account in the analysis. One limitation is topographic variations. Another factor is natural climate changes, which has severely influenced outdoor targets. In addition to attenuation, the overall Lambert change of targets is consistent, the whole uniformity of targets is better. To avoid these effects, average values calculated in image windows and multi-point radiation calibration based on large rectangular reflectance targets were employed. Otherwise 8-groups points of gray scale targets were used to validate calibration coefficients.

![Figure 2. Large rectangular reflectance targets and the reflectance annual attenuation](image2)

![Figure 3. Multi-grayscale targets and the reflectance annual attenuation](image3)

3.2. Atmospheric parameters measurement

CIMEL-318 sun spectrophotometer was used to obtain atmospheric optical properties. According to the Lambert-Beer law, the sun perpendicular incidence irradiance which permeates the atmosphere, and reaches the ground can be expressed as:

\[
E(\lambda) = \left(\frac{d_0}{d}\right)^2 \cdot E_0(\lambda) \cdot \exp[-m \cdot \tau(\lambda) \cdot t(\lambda)]
\]

(4)

\( E_0(\lambda) \) is the sun direct radiation spectral irradiance upper limited height of atmosphere wavelength \( \lambda \) in the solar-terrestrial mean distance. \( d_0 \) is the mean solar-terrestrial distance, \( d \) is the actual solar-terrestrial distance when observing, \( m \) is the atmospheric optical quality, \( \tau(\lambda) \) is the total atmospheric optical thickness. \( t(\lambda) \) is the absorbed gas transmissivity, when using the sun spectrophotometer to measure, the last formula can be converted to the ratio of signal value that is measured by the sun photometer to the sun incidence value.
The Synchronous atmospheric aerosol measurement time is 10:00-16:00 Beijing time, the flight time is 12:30-13:00 Beijing time. Langley method is used to inverse the aerosol optical depth, aerosol optical depth as shown in figure 4.

4. Results

4.1. Test flights
Extensive test flights with digital photogrammetric cameras - SWDC were carried out at the test field in 2011. The SWDC consists of four high resolution optical cones. The technical indicators are shown in table 1.

4.2. Calibration and results analysis
Reflection characteristics of artificial targets were analyzed according to the observed ground reflectivity data and atmospheric optical characteristics parameters obtained from 6Sv radiation transfer model. Apparent radiance value was calculated. Relationship between DC value of flight images and actual apparent radiance value of ground pixels were framed. Large-area reflection coefficient targets were used as DC value sampling points and DC mean value of multiple sampling points of each channel of images were extracted. Calibration coefficients were calculated according to multiple points.

Table 1. Technical parameters of SWDC

<table>
<thead>
<tr>
<th>Sensor</th>
<th>SWDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>Multi-head</td>
</tr>
<tr>
<td>f(mm)</td>
<td>35mm/50mm/80mm</td>
</tr>
<tr>
<td>Pixel size (μm)</td>
<td>6.8μm /9μm</td>
</tr>
<tr>
<td>Image size</td>
<td>13K×11K/11K×8K</td>
</tr>
<tr>
<td>Distortion</td>
<td>&lt;2μ</td>
</tr>
<tr>
<td>FOV along track</td>
<td>74°/49°</td>
</tr>
<tr>
<td>exposure time</td>
<td>1/320,1/500,1/800</td>
</tr>
<tr>
<td>aperture</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Using gray-scale target can form multi-point verification. The apparent radiance that is inversely obtained according to calibration coefficients and verification points DN value is comparable with sensor apparent radiance obtained through radiation transfer simulation, then relative difference can be calculated. In the purpose of analysing different height effect and relationship between the response of sensors to targets and measured surface reflectance, two flight heights were performed. As shown in figure 6, the results show that the linear relationship between response values of sensors and measured values of ground reflectance.
According to the DN value of various gray targets and measured surface reflectance value, apparent radiance in 1km, 2km flight height obtained using radiation transfer models are compared with the radiance value obtained inversely with calibration coefficients, and the relative difference is less than 8%. The results show that good agreement of individual band and better accuracy of 2km flight height than 1km flight height. So the calibration precision is relevant to flight height, it is sensitive to GSD.

5. Conclusions
This paper adopts a method based on artificial targets with different gray scale to conduct in-flight radiation calibration for digital photogrammetric camera. The performance of artificial targets is tested, and the annual attenuation of targets is analyzed. The linear correlation between the sensor response and targets reflectance is good. The apparent radiance simulated by radiation transfer model is compared with the inverse result using calibration coefficients, the uniformity of each band results of different flight height is good, while the sensitivity of GSD needs further verification. The influence of seasonal changes of surface features and uncontrollable natural factors reduces when permanent artificial targets are used rather than natural targets, which is a very effective method of analysing the calibration results of sensors. The calibration experiment has certain significance in using aviation digital cameras to conduct quantification remote sensing application.

Acknowledgements
The work presented here was supported by National 12th Five Year Civil Space grant Y1K00200KJ, Y1Y00500GF, Independent Research and Development grant Y1H1020034 and National Natural Science Foundation grant 40901230.

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