Radiometric correction of Spectral Camera data in general

1 Introduction

The radiometric correction process is in practice invisible to the user after having correctly defined parameters for correction and scaling. However user should be aware of the equations and units in order to understand the process.

As a result of radiometric correction image data is available in radiance or spectral radiance. Sometimes it seems to be very difficult to get right terms and units for the radiometric quantities. This is true even among people who have been working in the field of radiometry for decades. Some further reading about radiometric quantities is available in references.

2 Data and parameters to work with

To do a radiometric correction we need to have

- raw data,
- a calibration coefficient file (.cal),
- dark frame (same mode parameters as in raw data)
- knowledge of integration time

Two most important parameters, which should be the same during all of these measurements are *temperature* and *noise* behavior of the system. Changes in the first cause offset errors between the data sets resulting in false signal interpretation. The latter causes unexpected spikes in the data, which cannot be canceled out. This is especially critical on spectral channels having lowest response and thus highest radiometric correction gains, because the gain also multiplies the amplitude of noise if present. The raw data measurement and dark frame must be recorded using same integration time.

3 Units and scaling

3.1 Raw data and dark frame

Both raw data and dark frame is presented in data numbers (DN). For example if a 12-bit AD conversion is applied, resulting in a range from 0 to 4095 DN. Dark pixel correction is applied to the image by subtracting the signal on a dark frame from a signal on a raw data frame. This must be done on pixel-by-pixel basis. Possible offset or noise differences between these data sets will result in false signal interpretation or additional signal variation, respectively.

3.2 Calibration file

When making the calibration file (.cal), the scaling of values are computed according to radiance source response information. The response of the source is given in spectral radiance. Typically the units are *µW/cm^2-sr*-nm or *W/m^2-sr-um* (10 µW/cm^2-sr-nm = 1 W/m^2-sr-um). If the unit is different, this will also cause different unit in radiometrically corrected output data. Basically there should be also time unit ms marked cause the calibration coefficients are normalized to time 1 ms. So the unit should be µW-ms/cm^2-sr-nm More information you can find in example later in chapter 5. For some reason this time unit is usually left out.

The calibration files include correction gain for each pixel in data matrix and a linearity correction vector (4096 numbers) for raw data values. Like in this case no linearity correction is required and therefore it is not delivered. The calibration file is prepared according to calibration measurements and source response file. After the file is prepared, user has no control to these values. Assuming that the response file was given in units or *µW/cm^2-sr-nm*, the units of the gain coefficients in calibration file are *(µW-ms/cm^2-sr-nm)/DN*. The reason why the coefficients are normalized to integration time is that we can apply these coefficients to any data as long as we know the integration time.

3.3 Possible additional scaling

Because the results are typically presented on a computer display which can handle only integer values, it's sometimes necessary to do additional scaling for the data. This is done according to the prior (or trial-and-error) knowledge of the spectral radiance range in the data. To get best resolution for the results is to scale the data according to maximum values in the image. This is actually normalization of the results to a desired range.

4 Equations in radiometric correction

In radiometric correction process a spectral radiance for a single calibrated pixel is computed according to equation 1.

$$P_c = \frac{P_r \cdot G}{T_i \cdot B_w} \text{, in which} \tag{1}$$

P_r Dark corrected pixel value (could be a sum of signal on several rows)

G Calibration gain for that pixel (could be an average of several gains)

T_i Integration time in milliseconds

B_w Bandwidth of spectral channel in rows

Assuming the response file of chapter 3.2 the units for spectral radiance P_c will be *μW/cm^2-sr-nm*. Note that values are normalized to spectral sampling per row, which is 0.60-0.65 nm depending on the location of the row within spectral range. If you want to get radiance (*μW/cm^2-sr*) you must multiply resulting value with spectral sampling of that row or an average of rows.

User can apply arbitrary scaling to displayed values. If data type of pixels is signed for example 16 bit numbers. This will result in a range of ±32767. The scaling is performed according to equation 2. This will give user a scaled spectral radiance

$$P_{sc} = 32768 \cdot \frac{P_c}{R_{\max}} \text{, in which} \qquad (2)$$

P_c Radiometrically corrected spectral radiance, units μW/cm^2-sr-nm

R_{max} Desired maximum radiance to be displayed

If now R_{max} is selected wisely to be e.g. 32.768, then displayed range is up to 32.768 *μW/cm^2-sr-nm*. For example 10 *μW/cm^2-sr-nm* will be 10,000 as displayed value.

5 Example

Let's have an example using real data and calibration file. First we need a dark frame. In Figure 1 is a noisy one, but something which is a good example what happens in real world.

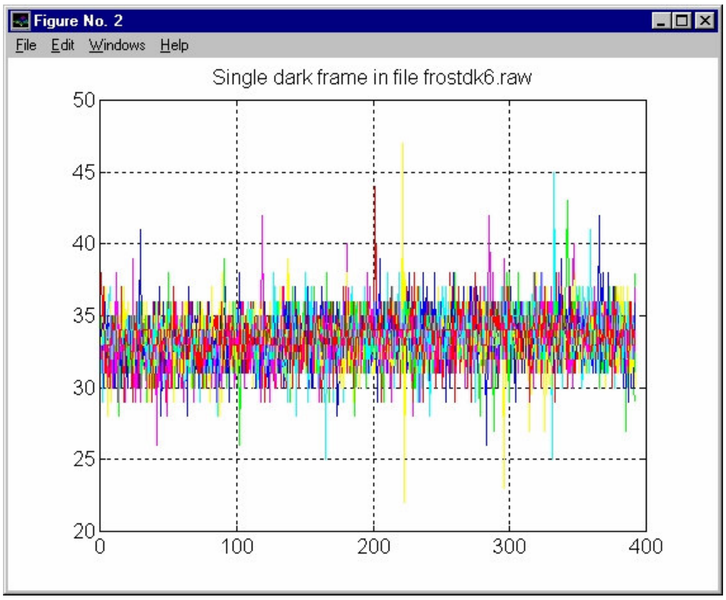

Figure 1. The sample of noisy dark frame.

Data was acquired using configuration of 25 channels. Each one was 4 rows in width and the integration time was 23.6 ms. For our simple example purposes we can estimate a dark pixel value of 33 DN.

Let's now select one of the spectral channels (#3) for this example. In configuration it's defined to be from 490.96 to 497.44 nm and hitting rows from 42 to 45 on detector. We need to have knowledge of calibration gains for these rows. In figure 2 we have spatial plots of gains on each 4 rows. Note that since we are on a rapidly changing slope of sensor response, there is variation in the gains from one row to another. Averaged gain for selected spectral channel is shown in figure 3.

Let's no pick up one point within FOV, for example column #50. The average gain for that column (and rows) is ca. 1.76 in the averaged gain curve of figure 3.

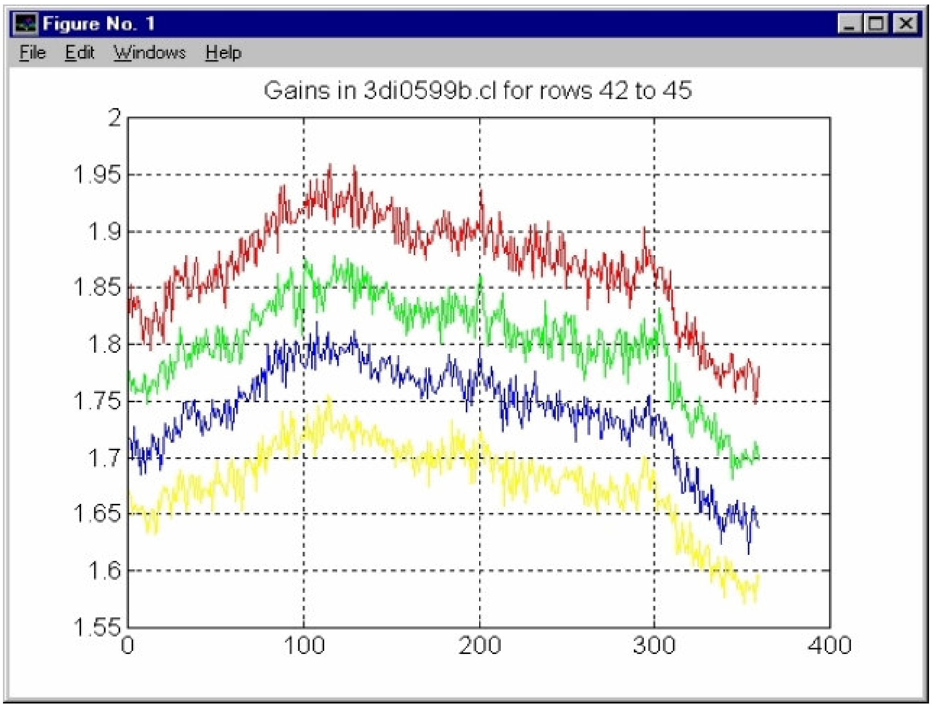

Figure 2. Calibration gains for rows #42 to #45.

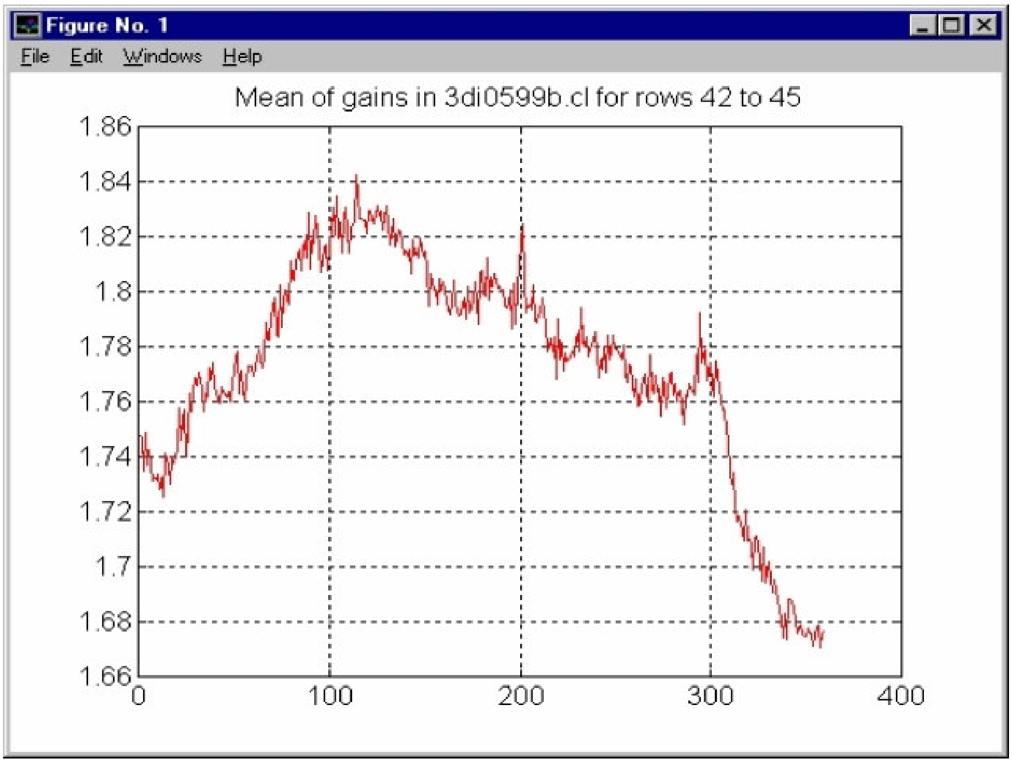

Figure 3. Average of calibration gains for rows #42 to #45.

Last, but not least we need to have raw data. In figure 4 is raw data on rows #42 to #45 from a file recorded in flight with the same configuration as the dark frame. Note that this signal is a sum of 4 rows. Ignore the vertical cursor line.

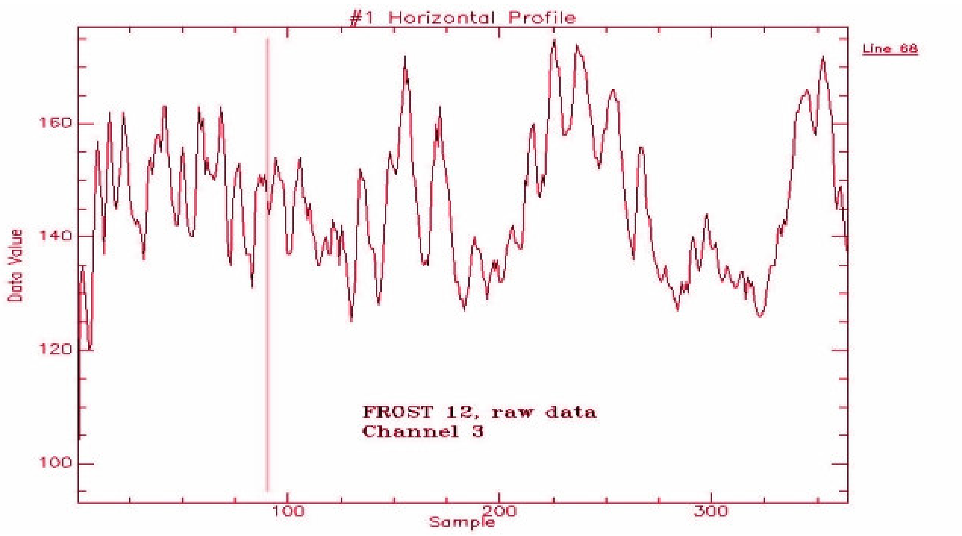

Figure 4. Sample summed raw data on rows #42 to #45

Now recall that we selected column #50 to be used in our example. The summed raw data value appears to be ca. 150 DN in Figure 4.

When we define that R_{max} of 32.768 will be used, we have enough information to complete this example. First we calculate the spectral radiance for this pixel according equation (1).

$$P_c = \frac{P_r \cdot G}{T_i \cdot B_w}$$

$$P_c = \frac{(150-33)DN \cdot 1.76(\mu\mathrm{W\text{ - }ms/cm^\wedge 2\text{ - }sr\text{ - }nm)/DN}}{23.6ms \cdot 4}$$

$$P_c = 2.18\mu\mathrm{W/cm^\wedge 2\text{ - }sr\text{ - }nm}$$

Then we use equation (2) to get scaling

$$P_{sc} = 32768 \cdot \frac{P_c}{R_{\max}}$$

$$P_{sc} = 32768 \cdot \frac{P_c}{R_{\max}}$$

$$P_{sc} = 32768 \cdot \frac{2.18\mu\mathrm{W/cm^\wedge 2\text{ - }sr\text{ - }nm}}{32.768\mu\mathrm{W/cm^\wedge 2\text{ - }sr\text{ - }nm}}$$

$$P_{sc} = 2180$$

From Figure 5 on column #50 we can check that the value is c. 2180. Again ignore the vertical cursor line. If we now want the get radiance, we need to multiply the spectral radiance with the spectral sampling on that line. Let's use for example value 0.6 nm. Thus the radiance *L* is

$$L = 2.18\mu\mathrm{W/cm^\wedge 2\text{ - }sr\text{ - }nm} \cdot 0.6\mathrm{nm}$$

$$L = 1.31\mu\mathrm{W/cm^\wedge 2\text{ - }sr}$$

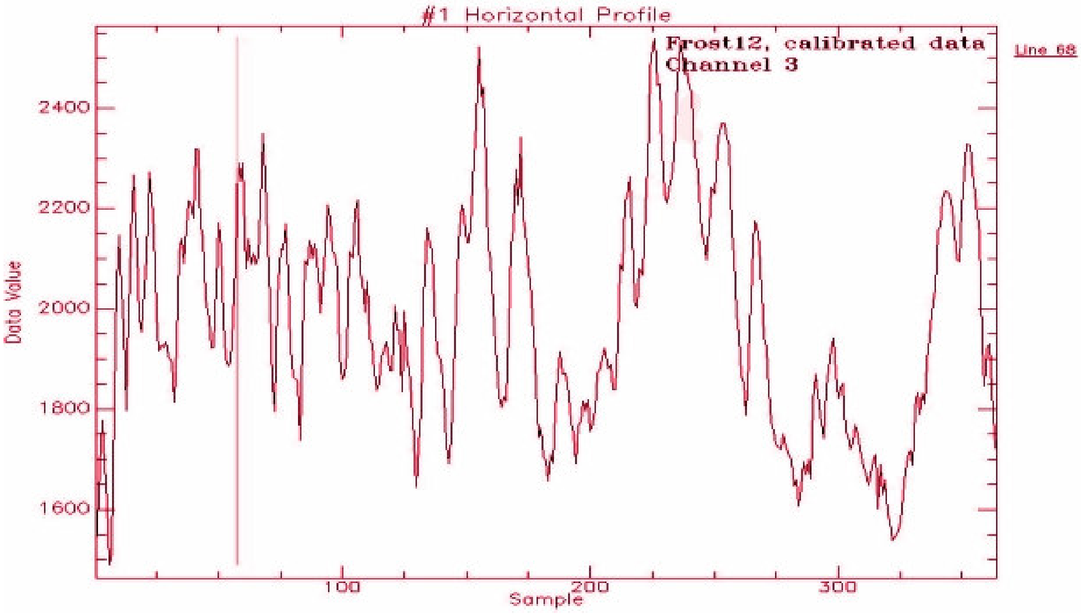

Figure 5. Sample summed raw data on rows #42 to #45

6 Notes

When one is using CCD detector one must remember existing features in such detectors. One of these is the possible required smear correction, which ought to be done for raw data even before the dark current subtraction.

7 References

1. William L. Wolfe, “Introduction to Radiometry”, SPIE Optical Engineering Press, 1998.
2. Norman S. Kopeika, “A System Engineering Approach to Imaging”, SPIE Optical Engineering Press, 1998.
3. Philip N. Slater, “Remote Sensing Optics and Optical Systems”, Addison-Wesley Publishing Company, 1980.