Introduction

CCD-spectrometers are extremely versatile instruments which are widely used in different applications today. While their popularity is very well justified (especially for method development or method testing) their limitations are less familiar. The main error sources of those instruments are:

1. (Dark current. Easy to compensate.)
2. Stray light. The stray light can be determined using a monochromator and a broad spectrum light source. This is a fairly complex and expensive experiment and out of the scope of this poster.
3. Detector nonlinearity. A cheap and fairly simple procedure to compensate detector nonlinearity is described here.

This procedure is aimed at those spectrometer users who a) actually need the higher precision and b) whose spectrometer does not provide the necessary correction function.

Setup

Configuration:

- Low integration times yield low spectrometer signals and high integration times should at least partly saturate the spectrometer.
- Required are lot of spectra at different integration times. We took up to 10 spectra at more than 1500 different integration times.

![spectrometer setup diagram](image)

Figure 1: Experimental setup. The stable light source is directly connected to the spectrometer.

Preconditions

The following assumptions should be fulfilled:

- the circuit (fig. 2) is a good approximation of the actual circuit used in the spectrometer
- the integration time is accurate and consistent
- Hamamatsu C10082CA CCD-spectrometer is used

Test for detector nonlinearity

The linearity of the detector is examined using the data collected with the setup described in Setup.

As the lamp is stable (concerning the intensity as well as the spectrum) all spectra \( I(\lambda) \) taken at different integration times and divided by the integration time \( \text{intTime} \) should yield the same spectrum and therefore flat lines in figure 3 b).

\[
\frac{I(\lambda)}{\text{intTime}_1} = \frac{I(\lambda)}{\text{intTime}_2}
\]

![spectral data](image)

Figure 3: a) Parts of the spectrum of a white LED taken at different integration times. b) Transmittance calculated using the light intensities at an integration time of 75ms for \( I_1 \).

Conclusions

- simple procedure to compensate for the detector nonlinearity
- ONE function for ALL pixels
- the linearity correction procedure can even be performed ‘in experiment’
- only the ADC-offset is temperature dependent

However the whole procedure is – up to now – only valid for Hamamatsu CCD spectrometers (Models C10082 and C10083). Avantes and TriOS spectrometers were also tested but failed due to either invalid assumptions or not enough integration times. Initial tests with OceanOptics spectrometers also failed due to software problems.

Linearity correction

![linear correction graph](image)

Figure 4: Intensities plotted against the integration time. Grey curves represent the data of a selection of pixels, Blue lines mark the selected pixels, Black line: average of the blue lines, Red dashed line: best linear representation of the black line.

- Select some pixels with suitable intensities at the highest integration time (blue in fig. 4).
- Average the intensities of the selected pixels (black).
- Find a suitable linear approximation to that curve (red dashed).

This linear approximation \( I_{\text{ave}} \) is the ‘correct’ value in the sense that it is a (better) linear representation of the physical facts than the values read from the spectrometer \( I \).

Therefore the values read from the spectrometer \( I \) can be corrected using a polynomial:

\[
I_{\text{corr}} = a_0 + a_1 \cdot I + a_2 \cdot I^2 + a_3 \cdot I^3 + \ldots + a_n \cdot I^n
\]

![error vs integration time](image)

Figure 5: Errors with different correction functions (different degrees of the polynomial).

![corrected data](image)

Figure 6: Corrected data.