DATA PROCESSING IN PRECISE SPECTRAL IMAGING

This application note presents basic data processing steps for color and other precise spectral measurements with a spectral imaging system consisting of stabilised light source, lens or fiber optics, ImSpector imaging spectrograph, area camera and PC.

1. CALIBRATION

a) Calibrate spectral axis by acquiring image(s) of spectral lamp(s), like Hg, Ne, Ar and Kr.
b) Block the light entering the lens or fiber optics, and acquire and store dark image.
c) Measure and store image of white reference, like ceramic or teflon plate. Spectralon is the best white reference material, but is of fairly high cost.

b) and c) must be repeated time to time depending on lighting and camera stability with aging and temperature variations.

2. SAMPLE REFLECTANCE

a) Acquire sample image(s).
b) Averaging. Maximise signal-to-noise ratio by averaging (by binning in camera or software) across as many rows as allowed without deteriorating the spectral resolution requirements. Usually at least the number of rows corresponding to the spectrograph slit width can be averaged.
c) Calculate sample reflectance for whole image (frame) or at wavelengths (i) and spatial pixels (c) of interest:

$$R_{ci} = \frac{sample_{ci} - dark_{ci}}{white_{ci} - dark_{ci}} \qquad [1]$$

This separates the sample reflectance from the system response and compensates for
- offset due to CCD dark current,
- light source color temperature drift, and
- lighting spatial non-uniformity across the scene line.

d) Additional offset compensation. There are usually also other small sources creating offset in the image than the CCD dark current. They are CCD frame shift smear and optical stray light. The offset due to these effects corresponds to the amount of light coming into the system. This offset level can be determined by using a long-pass filter to cut off incoming light across a small number of pixels in the beginning of each column (i.e. in the beginning of the wavelength range, see Fig. 1). Thus, ideally there should not be other than dark current generated signal at these pixels. The remaining signal after dark image subtraction is offset due to other factors. It can be compensated for by subtracting, column by column, the average value of the blocked pixels (avoffset) from all other pixels in the column:

$$R_{ci} = \frac{sample_{ci} - dark_{ci} - (avoffset_{sample})_c}{white_{ci} - dark_{ci} - (avoffset_{white})_c} \qquad [2]$$

Note that avoffset values must be calculated for each sample image and the white image separately. Choices for a blocking filter with ImSpector V7 are Schott GG-420 and Hoya L-42 absorbing below 410nm, and Kodak Wratten 2E absorbing below 415nm. UV blocking filters absorbing below 390nm (e.g. Schott GG-400) are suitable with ImSpector V8.

An example of the impact of the additional offset compensation is presented in page 2.

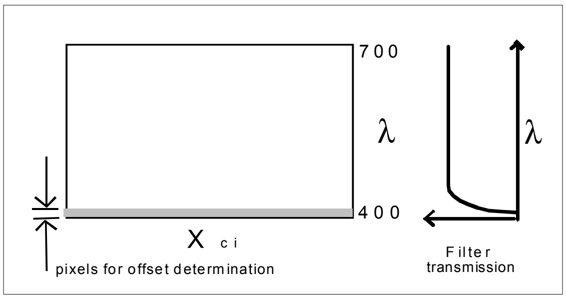

Figure 1. Schematic of long pass filter for offset compensation.

Dark, white and sample must all be measured with the same system parameters (integration time, lens F-number, temperature,….).

All these steps are not required in every application. In case only relative color or other spectral variations are measured, there is typically no need for spectral axis calibration and calculation of sample reflectance, but data analysis can be done on dark current corrected raw data.

3. APPLICATION SPECIFIC SPECTRAL DATA ANALYSIS

There are several methods for spectral data processing and the selection of the most suitable one depends on application.

- Correlation of the spectral intensity profile to the profiles of calibration (teaching) samples suits for verification of a limited and pre-known set of samples/colors.
- Calculation of color coordinates suits to measurement of color and color difference.
- Analysis of intensity ratios at predefined wavelengths or Principal Component Analysis (PCA) on limited or full spectral data suits to inspection/classification based on relative color differences and other relative spectral differences.

Example of additional offset compensation

A typical situation where the offset due stray light and frame shift smear may become of significance, is measurement of yellow/orange/red colors with a conventional CCD having low blue response and with halogen illumination producing low blue emission. Then the signal in the blue area in the image is very low in comparison to other areas and offset signal may become significant in proportion to the blue signal from the target. If not compensated for, the offset can cause incorrect reflectance value in the blue.

Fig. 2A shows raw spectra of blue (B), yellow (Y) and red (R) samples, acquired by 12 bit standard CCD camera with 420 nm cut-on filter and halogen lighting. Blue/red ratio in the illumination was increased by a factor of about 2 by using the lamp with a red attenuating filter. Fig 2B shows the offset remaining after dark image subtraction. Fig. 2C presents reflectance spectra calculated according equation [1]. Incorrect increase in reflectance can be seen in 420…480 nm in yellow and red spectrum. The same reflectance spectra calculated according equation [2] are shown in Fig. 2D

Average value of pixels in 400-410nm are used, column by column, for offset compensation.

The significance of this offset becomes the less the flatter the spectral system response is. CCDs with optimised high response across the visible are available from Sony and used in e.g. Pulnix and JAI cameras. Also, Texas Instruments virtual phase CCDs, used by e.g. Cohu and DVC, have good blue response. The best performance is achieved with back-illuminated CCDs, cameras manufactured e.g. by PixelVision. Secondly, halogen lamp emission spectrum can be flattened with yellow/red attenuating filter. Xenon lamp inherently produces fairly flat spectrum across the visible.

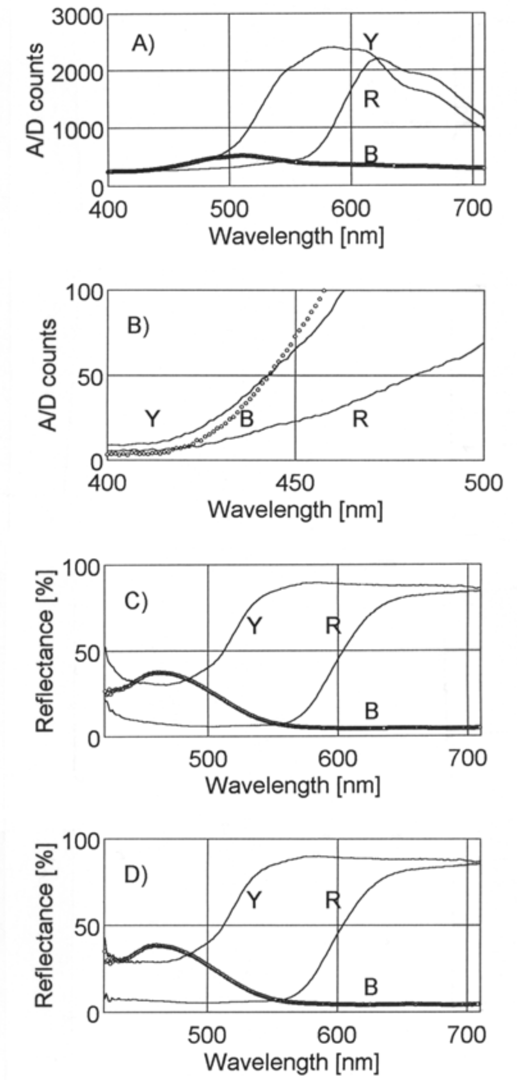

Figure 2. Example of additional offset compensation. Raw spectra (A), offset after dark image subtraction (B), reflectance with only dark image subtraction (C) and with additional offset compensation (D). Wavelength axis in C) and D) starts at 420 nm.