TECHNICAL NOTE 2022_9 – WHITE AND DARK REFERENCE USE AND IMPORTANCE IN HYPERSPECTRAL IMAGING DATA PROCESSING

Introduction

So called white and dark references are routinely measured and collected during hyperspectral reflectance scans and measurements, where such can be collected. This technical note describes the reason for collecting this data, the use of it in data processing and the typical means of how to measure and collect this data.

WHITE REFERENCE

> *A measurement (a scan) of a uniform target with known reflectance over the wavelength range – usually a target as close to 100% reflectance as possible (see fig. 1). An example of a commercial white reference material for VNIR and SWIR ranges, used in HSI is Spectralon. (https://en.wikipedia.org/wiki/Spectralon), If a dedicated white reference material can not be used for example in industrial applications, then it is possible to use either a material, which approximates a white reference, like a matt Teflon plate, or in theory any material, for which the reflectance spectrum is known.*
>
> *MWIR and LWIR wavelength ranges require a different type of white reference, for example a sandblasted aluminum plate which acts as a diffuse reflector.*

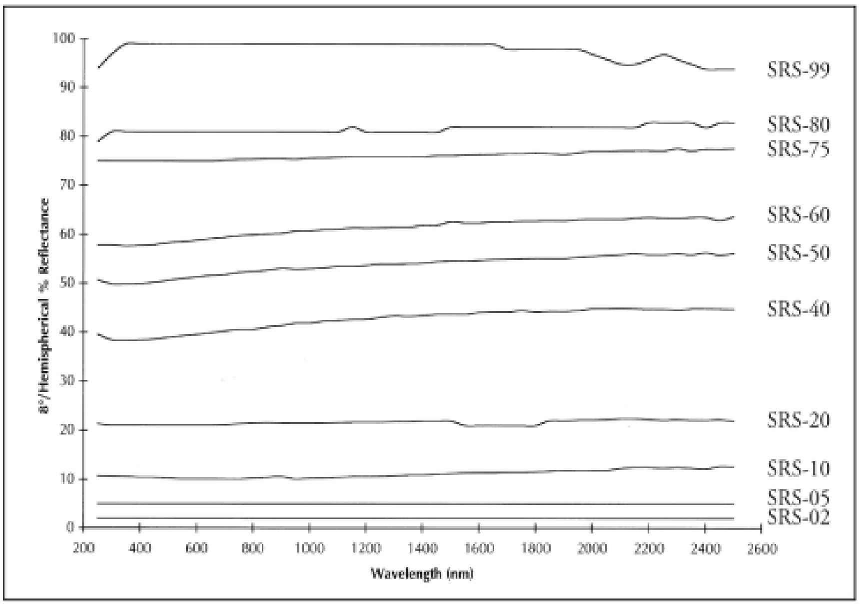

Figure 1. Hemispherical spectral reflectance factors for spectralon standards with different reflectances.

DARK REFERENCE

> *A measurement, collected with no light entering and hitting the camera detector. It is integration time dependent noise of detector not due to light and must be subtracted from data. Also called dark current. In MWIR and LWIR*

applications the dark signal is the signal the camera sees, when looking at an object at ambient temperature, with an emissivity $\varepsilon = 1$. This can be done either by looking at cold reference target or by closing the shutter.

WHITE AND DARK REFERENCE MEASUREMENT INTERVALS

The interval between measurements of the white and dark references depends on the application, the stability of the camera and the environment. In scanner use both references are typically recorded and stored for each individual scan as it is easy to do. In industrial use, if the applied processing model is robust enough, the references can be measured a few times per day, only once a week or even less.

Background

The output signal for a single pixel from a hyperspectral instrument can in general form be given as:

$$S(\lambda, x) = R(\lambda, x) \cdot I(\lambda, x) \tag{1}$$

Where $S(\lambda, x)$ is the raw, measured spectrum on a single spatial pixel x along the FOV (field of view) of the detector at wavelength λ, $R(\lambda, x)$ is the reflectance of the target material at a position x along the field of view of the camera at wavelength λ and $I(\lambda, x)$ is the instrument response function at a position x along the field of view of the camera at wavelength λ .

The instrument function $I(\lambda, x)$ is a function of the physical instrument – the optics and the detector – and of the illumination on the target. (This instrument function is determined by radiometric calibration for applications in which white reference measurements are not possible e.g. self-emitting objects like displays or in remote sensing)

The purpose of using white and dark reference measurements is to retrieve the reflectance $R(\lambda, x)$ of the target material by removing the instrument and illumination functions. By retrieving the material property, reflectance, the data is comparable between different instruments.

Method

Retrieving the reflectance of the target, also called "*normalization to reflectance*" is done in two stages:

1. Removal of the detector offset signal, i.e., the background dark signal, also called dark current.
2. Comparing (dividing) the measured signal to the signal of a known reflectance target (the white reference) and from that retrieving the reflectance of the target.

REMOVAL OF DARK SIGNAL

Removing the dark signal before doing anything else is required, because the detector of the camera will record a low signal, called a dark offset, even when no light hits the detector. For a 100% dark target the output signal still is > 0 DN (DN = digital number).The dark reference measurement is acquired by recording several image lines, e.g. 100, while no light hits the detector. This is typically done by closing the camera shutter. In case there is no shutter, then a lens cap or other object can be used to block the light from entering the camera. The recorded dark signal data is then averaged over time to eliminate time-dependent, or temporal noise. This dataset corresponding to a single image line with the full detector can then be subtracted from each scanned raw image line, detector pixel by detector pixel. It is important to notice that the subtraction is done pixelwise, as the camera detector also has pixel-to-pixel variation, which must be accounted for.

$$S_{dark}\,(\lambda,x) = S(\lambda,x) - Dark(\lambda,x) \tag{2}$$

Where $S_{dark}\,(\lambda,x)$ is the measurement result with the dark offset signal removed and $Dark(\lambda,x)$ is the recorded dark reference measurement.

NORMALIZING TO REFLECTANCE

Retrieving the reflectance of the target is done by comparing (dividing) the dark-removed signal of the target to a dark-removed signal of another known target, the white reference. The white reference target in the scanner is usually a flat object integrated on the scanning table, covering the full FOV of the camera with a reflectance very close to 100% over the full wavelength range of the camera. In scanner tables it is often scanned automatically. A number of image lines, e.g. 100, is recorded over the white target and averaged over time to eliminate noise. If the white reference is moving during the scan, the signal is spatially averaged over the white reference tile to eliminate dust specks etc.

The reflectance of the target is then

$$R(\lambda,x) = \frac{S_{dark}\,(\lambda,x)}{White(\lambda,x) - \;Dark(\lambda,x)} \tag{3}$$

Where $R(\lambda,x)$ is the reflectance of the target material at a position x and $White(\lambda,x)$ is the recorded measurement over the white reference. This ratio considers and removes the effects of the spectral and spatial responses of the optics, the detector, and the target illumination. The white reference reflectance is assumed to be ~100% over the full wavelength range.

PRACTICAL USE

In practice, the normalization is done for each image line, detector pixel by detector pixel, by the following simplified calculation:

$$R(\lambda,x) = \frac{S(\lambda,x) - D(\lambda,x)}{W(\lambda,x) - D(\lambda,x)} \tag{4}$$

Where $S(\lambda,x)$ is the measured, raw signal of the target, $D(\lambda,x)$ is the measured and averaged dark reference signal and $W(\lambda,x)$ is the measured and averaged white reference signal.

USE OF GRAY REFERENCE INSTEAD OF WHITE REFERENCE

The white reference usually determines the maximum integration time which can be used without saturation of the recorded signal. If the reflectance difference between the target sample and the white reference is large, then the signal level from the sample will be low, resulting a decrease of SNR (signal to noise ratio). To improve the SNR (see Technical Note TN2021_8_SNR_v1 for an explanation of SNR) a grey reference, instead of a white reference, can be used (see fig. 1). In that case the reflectance of the sample is calculated as

$$R(\lambda,x) = \frac{R_g \cdot (S(\lambda,x) - D(\lambda,x))}{(W(\lambda,x) - D(\lambda,x))} \tag{5}$$

Where R_g is the reflectance of the grey target, e.g. 0,5 or 50%.

USE OF DUAL INTEGRATION TIME INSTEAD OF GREY REFERENCE

If a grey reference is not an option, and only a white reference can be used, then the SNR can be improved by using dual integration time. Dual integration time means that the sample is measured with a longer integration time than the white reference, still leaving the signal unsaturated for both measurements. This raises the signal level of the sample measurement and improves the SNR. The reflectance is then calculated as

$$R(\lambda, x) = \frac{t_W}{t_S} \cdot \frac{S(\lambda, x) - D(\lambda, x)}{W(\lambda, x) - D(\lambda, x)} \tag{6}$$

Where t_W is the integration time for the white reference and t_S is the integration time for the sample.

PSEUDOCODE FOR NORMALIZING TO REFLECTANCE

```
# Pseudocode for calculating reflectance from hyperspectral data.
# This algorithm assumes that integration times for sample and
# white reference are equal
#
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#
# For clarity this algorithm is expressed as FOR-loops. In practice, most
# computing environments offer very efficient matrix manipulations
# to replace FOR-loops.
#
# TERMINOLOGY
#
# Frame: One image line in the output image. A single image line
#   consists of a full detector frame capture, with the spatial
#   x-axis and the wavelength y-axis. One detector columns contains
#   the spectrum for one spatial pixel
# nBands: number of wavelength bands in the data
# nLines: number of image lines (frames) in the data
# nSamples: number of spatial pixels across the image swath
# R_ref: reflectance of the white or gray reference in use; 0 - 1
# T_s: Integration time for sample measurement
# T_w: integration time for white reference measurement
# NOTE If integration times for ample and white reference are equal,
# then the same dark reference can be used for both.

# Raw scan data is stored as 16-bit unsigned integer and needs to be
# converted to floating point at some point for the averaging
# and the calculation of reflectance

########
# Calculate dark reference scan average:
# average data pixelwise over time
darkref_sample(*, *) = 0  # reset array to zeros
darkref_white(*, *) = 0

# open data files on disk for reading
open_file_for_reading(raw_data)
open_file_for_reading(whitescan)
open_file_for_reading(darkscan_sample)
open_file_for_reading(darkscan_white)  # might be the same file as 'darkscan_sample'

# open the output file for writing
open_file_for_writing(reflectance_image)
```

```

For each spatial pixel in nSamples
    For each wvl in nBands
             # if we have different integration times for white ref and
             # sample, then this has to be taken into account
             # otherwise they are the same data
        For each frame in nLines_darkref_white
            # sum values for each pixel in dark ref data of white ref
            darkref_white(spatial, wvl)=
                darkref_white(spatial, wvl)+darkscan_white(frame, spatial, wvl)
        For each frame in nLines_darkref_sample
            # sum values for each pixel in dark ref data of sample
            darkref_sample(spatial, wvl)=
                darkref_sample(spatial, wvl)+darkscan_sample(frame, spatial, wvl)
# calculate average of summed data for each pixel of detector frame
For each spatial pixel in nSamples
    For each wvl in nBands
        darkref_white(spatial, wvl)=float(darkref_white(spatial,
wvl)/nLines_darkscan_white)
             darkref_sample(spatial, wvl)=float(darkref_sample(spatial,
wvl)/nLines_darkscan_sample)

########
# Calculate white reference scan average:
# average data pixelwise over time and remove dark current
whiteref(*, *) = 0  # reset array to zeros
For each spatial pixel in nSamples
    For each wvl in nBands
        For each frame in nLines_whiteref
            # sum values for each pixel in white ref scan
            whiteref(spatial, wvl)=
                whiteref(spatial, wvl)+whitescan(frame, spatial, wvl)
# calculate average of summed data for each pixel of detector frame
# convert result to floating point when calculating average
For each spatial pixel in nSamples
    For each wvl in nBands
        whiteref(spatial, wvl)=float( whiteref(spatial, wvl)/nLines_whitescan ))
        # remove dark current from it
        whiteref(spatial, wvl)=whiteref(spatial, wvl)-darkref_white(spatial, wvl)

########
# Calculate reflectance of data
# Store result as floating point
# Take into account possible gray reference vs. white and difference in integration
# times
For each frame in nLines_image
    For each spatial pixel in nSamples
        For each wvl in nBands
            reflectance_image(frame, spatial, wvl)=
                R_ref * (T_w/T_s) * [float(raw_data(frame, spatial, wvl))-
darkref_sample(spatial, wvl)] /
                    whiteref(spatial, wvl)  # whiteref is already dark corrected
```

Note

In air- and spaceborne applications the procedure is different, since a white reference covering the full FOV cannot be measured. Here a radiometric correction based on a radiometric calibration of the camera together with an atmospheric correction algorithm is often used, to convert the raw measurement first to spectral radiance, and then to reflectance. Instead of an atmospheric correction, using a known reference target somewhere in the image to convert radiance data to reflectance can be used.

Version history

Version	Date	Author	Comments
1.0	2022-12-12	Rainer Bärs	
1.1	2022-12-28	Rainer Bärs	Included comments
1.2	2023-01-05	Rainer Bärs	Additional comments, added pseudocode section
1.3.	2023-01-12	Rainer Bärs	Fixed typos in pseudocode, added clarifications to pseudocode