TECHNICAL NOTE TN2021_8 - SNR

Introduction

This TN defines the SNR of a camera (signal to noise ratio), and which parameters may affect it.

SNR = SIGNAL TO NOISE RATIO

PET = POLYETHYLENE TEREPHTHALATE

SQRT = SQUARE ROOT

*X^2 = X * X*

DN = DIGITAL NUMBER

LWIR = LONG WARE INFRARED

NESR = NOISE EQUIVALENT SPECTRAL RADIANCE

NETD = NOISE EQUIVALENT TEMPERATURE DIFFERENCE

Article

Every sensors are noisy, and their ability to measure effective signal from their noise is quantified by an index, called SNR. SNR stands for Signal to Noise Ration, and is indeed the ratio of an effective signal over the signal of the sensors. A very good sensor would have a high SNR, whereas a poor one will have a low SNR.

At SPECIM, we calculate the SNR as follow:

(1) SNR = (mean(S) – D) / std(S – D),

where S is time series (values from all frames) and D is averaged dark.

Graphically, it can be represented as below, in Fig.1.

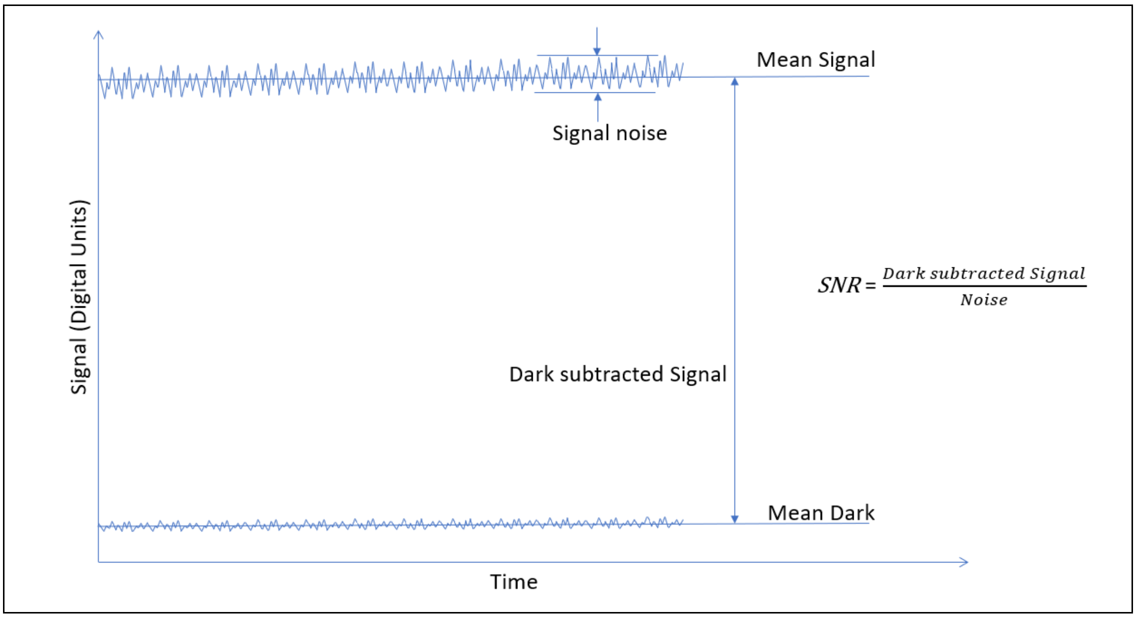


Figure 1: Graphical illustration of SNR calculation

Peak SNR

There is also mentioned of what is so called peak SNR. This is the SNR when the signal is close to saturation of the detector, meaning when filling the well capacity of the detector (i.e. a signal close to 4096 DN when using a 12 bits camera). This peak SNR is not necessarily achievable over the full spectral range during a data acquisition. Indeed, it depends on several factors:

- the spectral response of the camera (which depends on the optics transmission and the Quantum Efficiency of the sensor)
- the illumination
- the reflectance of the samples

All these together make the acquired raw data uneven, spectrally speaking, over the full spectral range. To illustrate this, in Fig.2 below is a typical white reference signal measured with a FX17, under halogen illumination. Those are raw data. As can be seen, the best SNR, on these data is at about, 1200 nm, and the worse at 1700 nm

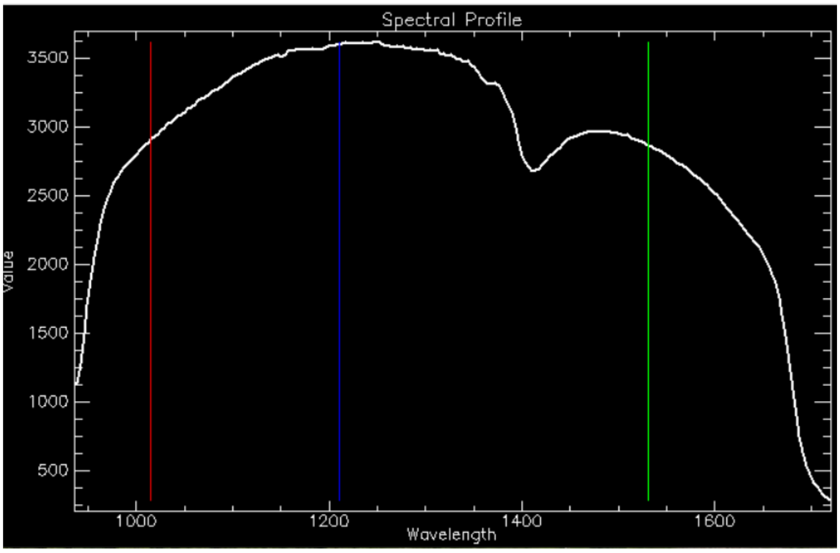
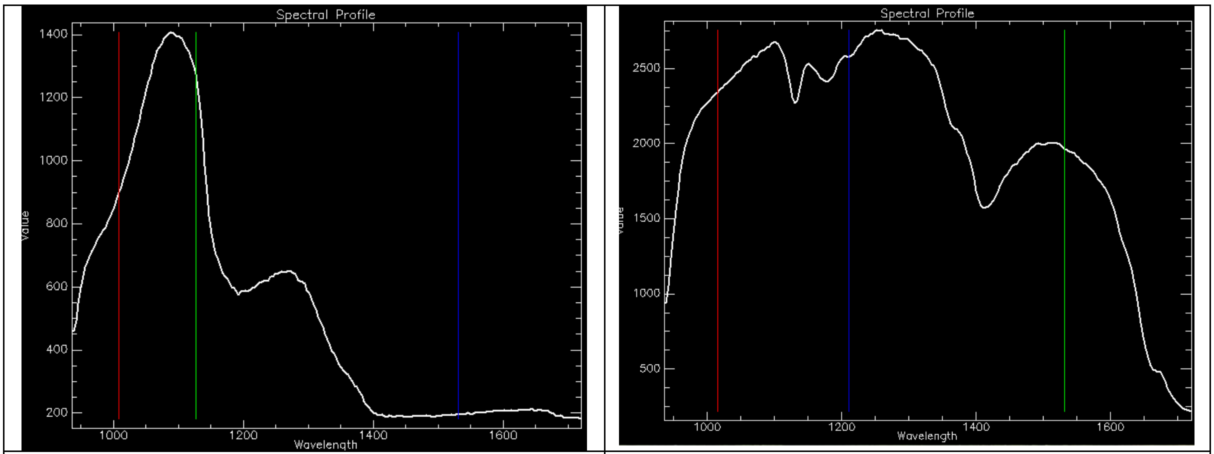


Figure 2: White reference raw signal measured by a FX17 under halogen illumination.

However, from this, it is crucial to understand that the SNR is not a question of wavelength, but is fundamentally related to the Digital number level (or how much the well capacity is filled by the signal). And the SNR is therefore strongly related to the sample which is measured. To illustrate this, we consider 2 examples: i) a meat sample, and ii) a plastic (PET) one (Fig.3).



Raw FX17 spectrum of a meat sample | Raw FX17 spectrum of a PET sample

Figure 3: raw spectra of meat and PET samples measured with FX17.

When measuring meat, the SNR of the FX17 (under halogen illumination) is best at 1092 nm and very low after 1400 nm, whereas when measuring PET it is best at 1252 nm and remains high from 1000 to 1600 nm (under similar illumination).

SNR from the camera manufacturer data sheet

Hyperspectral cameras are employing a sensor chip, and its performances are crucial for the whole system. Sensor chips have 3 types of noise:

1. Photon noise = sqrt(ep)
2. read out noise = er
3. dark noise = ed

The resulting total noise is then,

(2) et = sqrt(ep + er^2 + ed^2),

and the SNR is defined as

(3) SNR = ep / et

Those different components need to be interpreted carefully to thoroughly understand the behavior of cameras, and can help the users to choose the correct device depending on the needs.

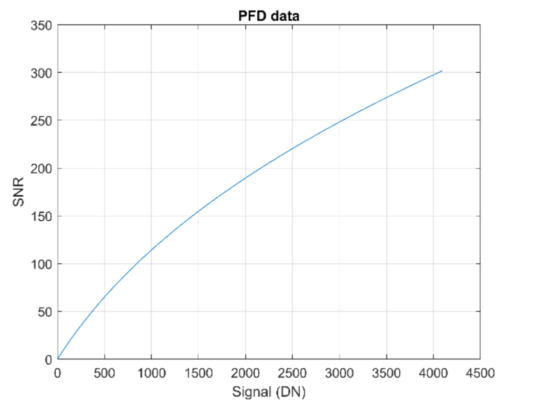
- For **high intensity signal**, when the well capacity of the detector can be filled, the total noise (et) can be approximated to sqrt(ep). It means that **SNR = ep / sqrt(ep) = sqrt(ep)**; and since we have a high intensity signal, the well capacity of the detector is filled, **ep = well capacity**.
- For **low intensity signal**, when only little of the well capacity of the detector can be filled, when for instance dark samples are measured, the total noise (et) can be approximated to sqrt(er^2 + ed^2), and here the reading noise of the camera has a very strong impact.

In the light of that, we can take 2 examples for SPECIM camera portfolio: the sCMOS and PFD devices. The well capacity of the PFD camera sensor is 90ke-, whereas the one of the sCMOS camera is 30ke-. Following the above mentioned approximation, the peak SNR of the PFD camera should be ca. 300:1, and the one of the sCMOS 173:1. The curves below match pretty well. **As a conclusion, for high intensity signal, the camera with the highest well capacity is best, in that case the PFD one.**

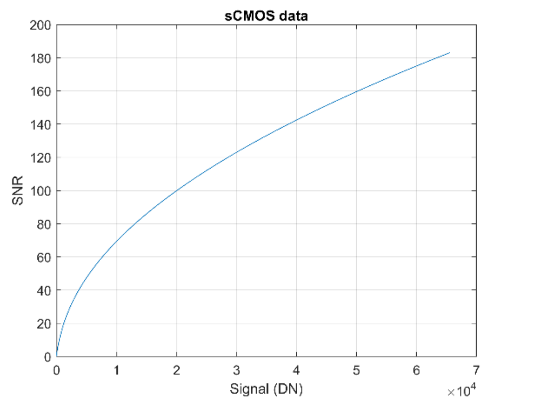
Now, considering still the same cameras, but measuring a signal peaking at 5% of the dynamic range. With the PFD camera (12 bits camera), that means a signal at ca. 205 DN, and the sCMOS (16 bits camera) at ca. 3300 DN. Looking at the curves below, the SNR of the PFD camera is ca. 25:1, whereas for the sCMOS camera it would be ca. 35:1. **It means that for low intensity signal, the sCMOS camera would be the preferred one.** The reading noise of the sensor embedded to the sCMOS camera is 1 e-, whereas for the PFD camera it is 110 e-.

It is also important to notice here that the above mentioned does not take into account the binning configuration, which has a very strong impact on the SNR (see the next paragraph).

PS: the PFD camera is a 12 bits camera (max DN is 4096), whereas the sCMOS one is 16 bits (max DN is 65 536 DN, hence the difference of X axis magnitude on both graphs below, Fig.4).



SNR curve vs DN for the PFD camera



SNR curve VS DN for the sCMOS camera

Figure 4: SNR curves vs DN for both PFD and sCMOS cameras.

Both Above SNR curves can also be plotted on the same graph.

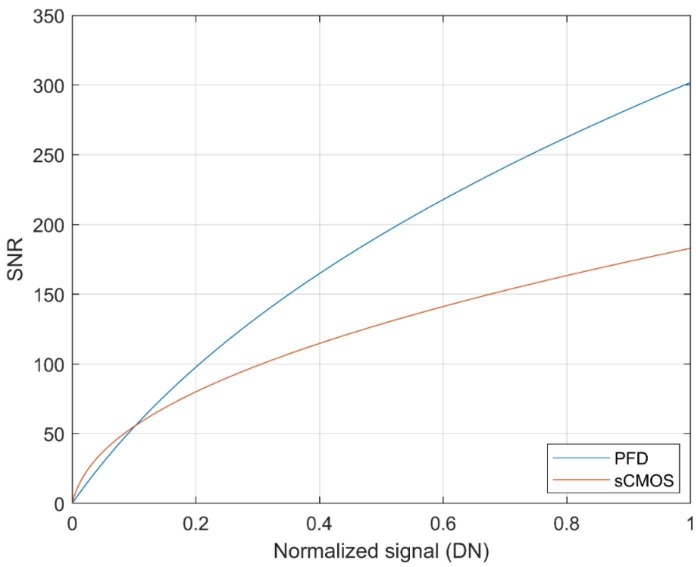


Figure 5: SNR curves of PFD vs sCMOS cameras in respect to the filling of the detector well capacity

SNR vs binning

There is another important factor to take into account: the binning configuration. Binning is the addition or averaging of several pixels together, and this can be effective in the spatial and spectral direction. The SNR of the sensor is directly increasing with the square root of the binning factor.

SNR(MXN) = SNR(1x1) x sqrt(MXN), with M and N the binning factors in the spatial and spectral direction, SNR(MXN) is the SNR in the MXN binning configuration.

Taking into account the figures of SPECIM FX10, the peak SNR(1x1) is 300:1, and SNR(1x2) is 420:1, 40% higher (as stated in the datasheet, as the recommended binning configuration is 1x2, and the well capacity of the sensor is 90 ke-).

For the thermal cameras: NESR and NETD

For thermal cameras, the concept of NESR (noise equivalent spectral radiance) and NETD (noise equivalent temperature difference) need to be introduced, and are widely used. Those numbers depict from an application point of view the performance of the device.

- NESR is the smallest spectral radiance contrast that can be resolved from the sea of noise. Any difference in spectral difference at target that is smaller than NESR cannot be resolved.
- NETD is the smallest temperature difference that can be detected form the noise. Any temperature difference at target that is smaller than NETD can not be detected.

Those numbers can be found on SPECIM LWIR hyperspectral cameras data sheet.

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Version history

Version	Date	Author	Comments
1.0	Feb 18th 2022	MMA	