May, 14th, 2016

Application note for CMS camera and CMS sensor users : Post-processing method for crosstalk reduction in multispectral data and images.

Vincent Sauget, Marc Hubert, Aurélien Faiola, Stéphane Tisserand
SILIOS Technologies, ZI Peynier-Rousset, Rue Gaston Imbert prolongée, 13 790 Peynier
www.silios.com

1 Introduction

CMS sensors and CMS cameras are made of a pixelated multispectral filter assembled on top of a standard commercial monochrome sensor. The pixelated multispectral filters are produced thanks to the SILIOS's COLOR SHADES® technology. Such a hybrid technology is more flexible and more scalable than a monolithic technology in which the multispectral filter is manufactured directly on the sensor's wafer (like for standard RGB sensors for instance). However it shows a higher level of crosstalk especially as the pixel size becomes smaller, because of the gap in between the surface of the filter and the surface of the sensor. To correct this effect, SILIOS Technologies developed a post-processing method to correct the crosstalk and related effects on reconstructed spectra. This paper details the principle of the mathematical method to perform the crosstalk reduction. The CMS sensor used in this example is a CMS-V sensor (8 bands + 1 panchromatic channel) which characteristics are depicted in annex A. It gives also an example of result to show the benefit of the method onto the images as well as on the spectra.

2 Principle of the post-processing crosstalk reduction method

The method is based on the correction of each pixel value by applying a linear combination of the neighbor pixels to remove the crosstalk.

The main steps of the method are the following:

- Measurement of the spectral response of all the pixels of the multispectral sensor.
- Calculation of the average spectral response of each spectral sub image.
- Estimation of the best crosstalk reduction coefficients to minimize the cross talk in the reconstructed sub-images.
- Use of these coefficients directly onto the macro pixels data to reconstruct the corrected sub-images.

2.1 Estimation of crosstalk correction coefficients

Each CMS sensor is characterized using a monochromator so that the spectral response of each pixel is known (with a step of 2 nm over the 400-1000 nm range). The following step consists to extract the spectral sub-images (one image for each of the 300 wavelengths) and to average the pixel response of each sub-image to get the mean-spectral-response of each spectral sub-image. In the case of the CMS-V sensor, there are 9 spectral sub-images: 8 band-pass filtered + 1 panchromatic filtered. The mean spectral response of the sensor's pixels is then known. The result is given in the figure 1.

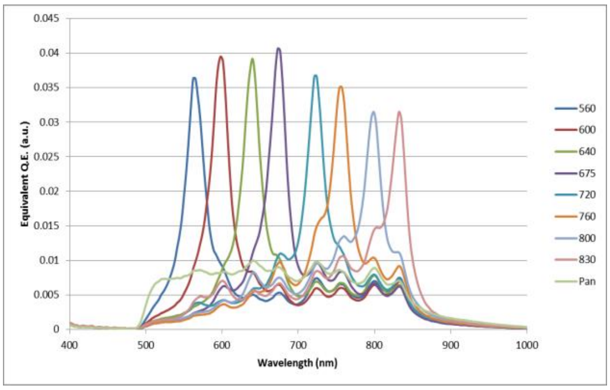


Figure 1: mean spectral response of the 8 spectral sub-images

The second step consists to define target spectral response (ideal response) for each spectral sub-image. We choose Gaussian functions specifying their central wavelengths and widths. The panchromatic channel is not corrected.

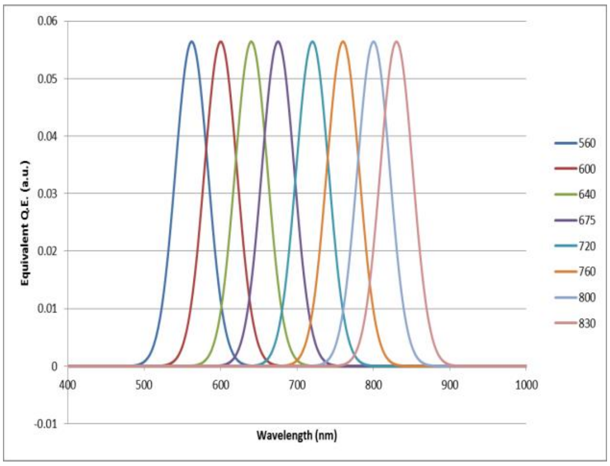


Figure 2: target spectral responses for the 8 spectral sub-images

Then we estimate the 81 linear coefficients (9x9) to reconstruct the spectral channels from the mean spectral responses of the spectral sub-images (we use the Generalized Reduced Gradient method). Finally, we apply these coefficients to the mean spectral response of spectral sub-images.

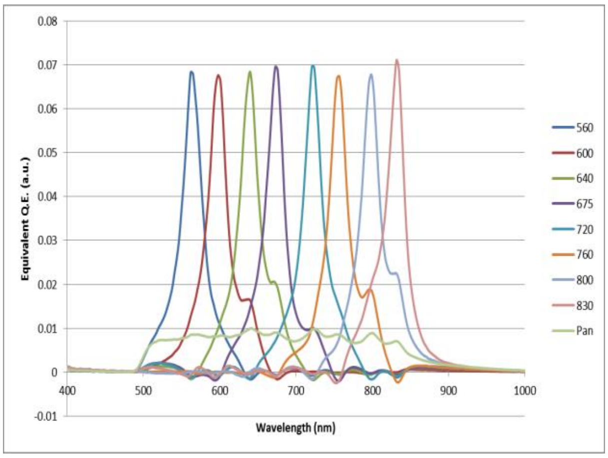


Figure 3: corrected spectral responses for the 8 spectral sub-images

2.2 Method verification

In this section, we detail mathematically the method and we verify it.

$Fr(\lambda)$	is the optical Flux
$QE_i(\lambda)$	is the Quantum Efficiency of a pixel filtered with the filter i
$QErec_i(\lambda)$	is the Quantum Efficiency of a so-called "virtual pixel" filtered by the reconstructed filter i
P_i	is the response of a pixel filtered with the filter i
$Prec_i$	is the response of a "virtual pixel" filtered with the reconstructed filter i

Let assume the following points:

- The optical flux is considered to be the same in all the 9 pixels of a macro pixel (3x3 pixels).
- Noises are negligible.
- The response of the pixels is linear (no saturation and no correction like antiblooming, gamma, etc.)
- The response of the optical filters is linear and only wavelength dependent.

We construct $QErec_i(\lambda)$ as linear combination of the $QE_i(\lambda)$ weighted by the crosstalk correction coefficients CC_{ij} :

$$QErec_i(\lambda) = \sum_j CC_{ij} \times QE_j(\lambda)$$

The response of a pixel i is given by the equation:

$$P_i = \int_\lambda Fr(\lambda) \times QE_i(\lambda)\, d\lambda$$

The response of a virtual pixel i is given by the equation:

$$Prec_i = \int_\lambda Fr(\lambda) \times QErec_i(\lambda)\, d\lambda$$

The following calculation shows that, in the same manner that we can apply the crosstalk correction coefficient to the real filters to reconstruct crosstalk-free virtual filters, we can apply these coefficients to the pixel values (within a macro pixel) to reconstruct crosstalk-free virtual pixel values.

We develop the expression of $Prec_i$:

$$Prec_i = \int_\lambda Fr(\lambda) \times QErec_i(\lambda)\, d\lambda$$

$$Prec_i = \int_\lambda Fr(\lambda) \times \left(\sum_j CC_{ij} \times QE_j(\lambda)\right)\, d\lambda \qquad \text{(replacement of } QErec_i(\lambda) \text{ by its formula)}$$

$$Prec_i = \sum_j \left\{ CC_{ij} \int_\lambda Fr(\lambda) \times QE_j(\lambda)\, d\lambda \right\} \qquad (CC_{ij} \text{ is independent of } \lambda)$$

The equation of $Prec_i$ is then:

$$Prec_i = \sum_j CC_{ij} * P_j$$

2.3 Application of the method

To be independent of the illuminant, we preferably normalize the mean spectral responses of the spectral sub images and we apply the correction to normalized multispectral images.

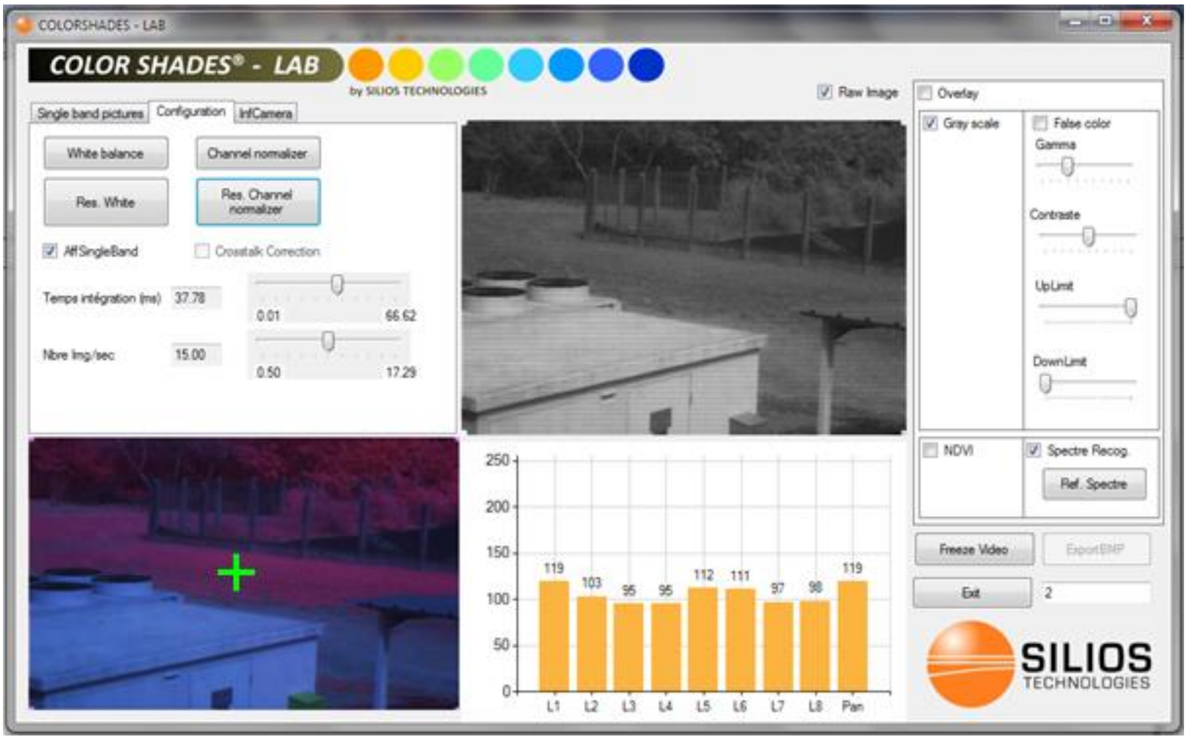
The crosstalk correction coefficients can be represented by a square matrix. This square matrix has N lines and N columns, with N equals to the number of spectral sub-images. For the CMS-V sensor, the matrix is 9x9 sized.

	Prec1	Prec2	Prec3	Prec4	Prec5	Prec6	Prec7	Prec8	Prec9
P1	1.93	0.01	-0.15	-0.09	-0.20	0.02	0.01	-0.16	0.00
P2	-0.06	1.82	-0.02	-0.26	-0.09	0.02	-0.07	-0.32	0.00
P3	-0.19	0.25	1.85	-0.04	-0.19	-0.11	-0.30	-0.13	0.00
P4	-0.09	-0.22	0.22	1.86	-0.24	-0.37	-0.16	-0.13	0.00
P5	-0.24	-0.08	-0.25	0.02	2.13	-0.36	-0.35	-0.21	0.00
P6	-0.13	-0.09	-0.14	-0.38	0.04	2.22	-0.50	-0.60	0.00
P7	-0.19	-0.17	-0.28	-0.19	-0.38	0.38	2.51	-0.19	0.00
P8	-0.33	-0.26	-0.21	-0.20	-0.30	-0.65	0.22	2.70	0.00
P9	0.30	-0.25	0.01	0.30	0.26	-0.12	-0.30	0.03	1.00

Table 1 : Example of crosstalk correction coefficient matrix for one particular sensor (CMS-V 1603001)

When extracting the spectral sub-images from the raw image, the linear combination is applied to each pixel using the 9 pixel values of the corresponding macro pixel.

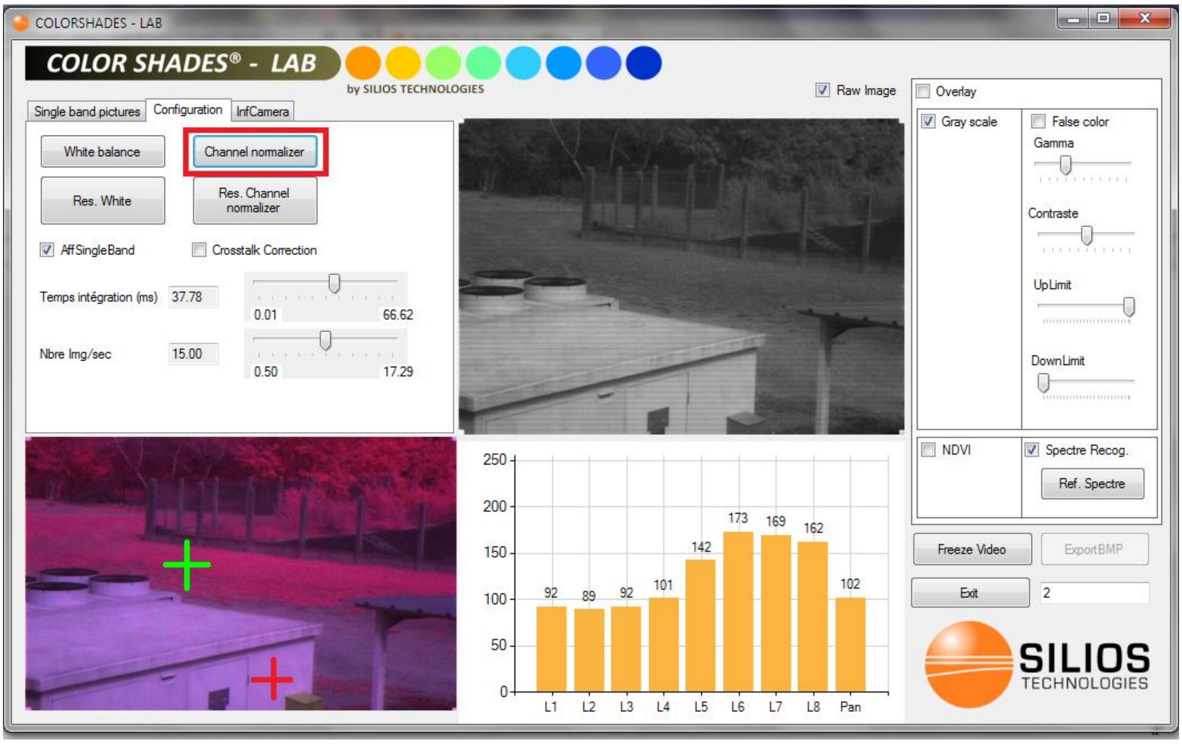
We give hereunder the example of a scene with vegetation (grass and trees) obtained with the CMS-V camera. Due to its spectrum sampling (550-830 nm), the camera CMS-V is particularly well-suited to detect the spectral signature of the chlorophyll. The picture 1 shows the visual interface of the SDK (Software Demo Kit) developed by SILIOS. The top-right image is the raw image (without any treatment). The bottom-left is a false color image, reconstructed from the 9 spectral sub-images (transformation of a 9 bands multispectral image into a RGB false color standard image). In the picture 1, no crosstalk correction is applied. The 9 band spectrum of the grass is given at the bottom right. The 8 first bars correspond to the 8 narrow spectral bands (from 550nm up to 830 nm) and the last one corresponds to the panchromatic sub-image.



☑ AffSingleBand
☐ Crosstalk Correction
Temps intégration (ms) 37.78 (0.01 – 66.62)
Nbre Img/sec 15.00 (0.50 – 17.29)
☑ Raw Image
☐ Overlay
☑ Gray scale
☐ False color
☐ NDVI
☑ Spectre Recog.
2

Picture 1: SDK graphic interface. Bottom: reconstructed false color image and grass spectrum before correction.

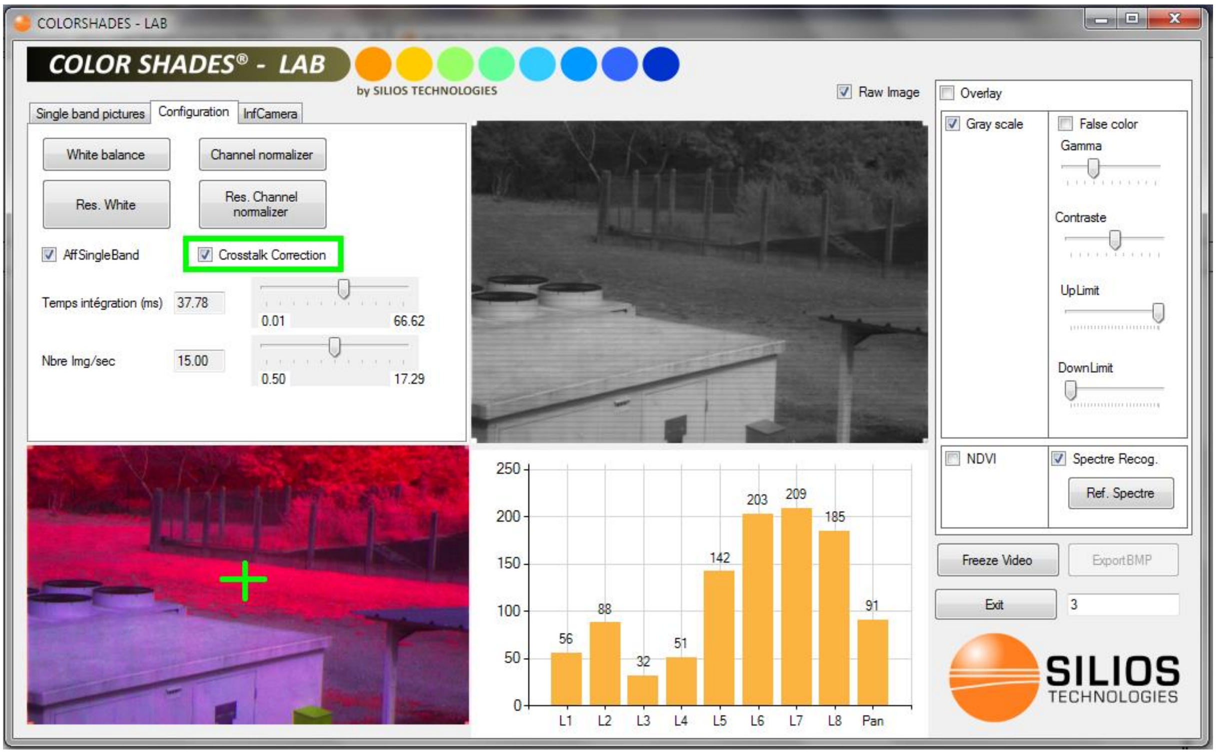
The picture 2 shows the false color image and the spectrum of the grass after channel normalization. The normalization is made into a “white” object in the scene (see the red-cross). It can be also made outside of the scene during a preliminary step.



☑ AffSingleBand
☐ Crosstalk Correction
Temps intégration (ms) 37.78 (0.01 – 66.62)
Nbre Img/sec 15.00 (0.50 – 17.29)
☑ Raw Image
☐ Overlay
☑ Gray scale
☐ False color
☐ NDVI
☑ Spectre Recog.
2

Picture 2: SDK graphic interface. False color Image and grass spectrum after channels normalization.

The picture 3 shows the false color image and the spectrum of the grass after crosstalk correction. The strong improvement in the false color image contrast can be seen. The spectrum of the grass is also highly improved. It shows clearly the high contrast in between the red channel and infra-red ones (called the "red-shift"). It shows also the classical contrast in between green and red channels.



☑ AffSingleBand
☑ Crosstalk Correction
Temps intégration (ms) 37.78
Nbre Img/sec 15.00
☑ Raw Image
☐ Overlay
☑ Gray scale
☐ False color
☐ NDVI
☑ Spectre Recog.
3

Picture 3: SDK graphic interface. False color Image and grass spectrum after crosstalk correction.

2.4 Implementation

To optimize the correction of the crosstalk in each produced sensor (or camera), SILIOS fully characterizes each of them and calculates their specific sets of coefficients. These coefficients are provided with each sensor or camera.

SILIOS provides a library (dll) allowing the user to apply the crosstalk correction method.

2.5 Uniformity consideration

In the here-above described method, the multispectral sensor is considered to be perfectly uniform regarding the spectral behavior of the pixels (wavelength centering, transmission, band width, …). In most case the non-uniformities over the sensor surface are negligible compared to the required accuracy of the spectrum measurement. In such case, a common set of crosstalk correction parameters is used and applied to all the pixels of the image. However, in certain cases (for very precise measurement or for large surface sensors for instance) these non-uniformities can't be neglected. In these cases the same method can be applied by splitting the image into parcels. Each parcel is considered to be uniform and a specific set of crosstalk correction coefficients is determined for each parcel. The size of the parcels can vary from the macro pixel size up to the image size. The parcels can be identical or can have different sizes and geometries. The process to be applied to each parcel is the same than the one described in this document for the full image.

3 Conclusion

The crosstalk correction method is a smart post-process treatment permitting a strong crosstalk reduction. It allows optimizing the image contrast and the local spectrum measurement. Its application provides data with negligible crosstalk pollution effects. Each sensor and camera is provided with its adapted set of coefficients allowing a perfect correction.

ANNEX A : Specification of the sensor CMS-V 1603001.

CAMERA IDENTIFICATION

Designation	CMS-V1
Technology	COLOR-SHADES
S/N	CMS16030001

ARRAY SPECIFICATIONS

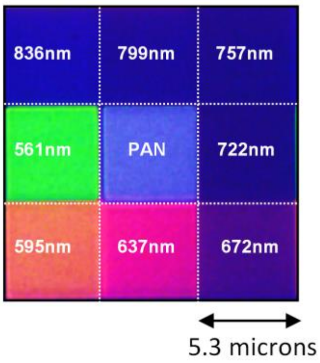
Array type	CMOS (Si)
Spectral band	400 to 1000 nm
Resolution	1280 (H) x 1024 (V)
Pixel pitch	5.3 µm
Pixel operability	> 99.85 % (1)

(1) Dead pixels : < 0.15% among which 0.10% used for alignment purpose in the 4 corners of the pictures.

FILTER SPECIFICATIONS

Macro-pixel size	3x3 bands
Wavelength range	550 to 830 nm typical
Type of pixel	8 colors (narrow bands) + 1 B&W
Band 1	λc : 561nm / FWHM : 30 nm / T_{max} : 57%
Band 2	λc : 595nm / FWHM : 29 nm / T_{max} : 57%
Band 3	λc : 637nm / FWHM : 28 nm / T_{max} : 57%
Band 4	λc : 672nm / FWHM : 27 nm / T_{max} : 58%
Band 5	λc : 722nm / FWHM : 26 nm / T_{max} : 54%
Band 6	λc : 757nm / FWHM : 26 nm / T_{max} : 52%
Band 7	λc : 799nm / FWHM : 25 nm / T_{max} : 50%
Band 8	λc : 836nm / FWHM : 26 nm / T_{max} : 47%
Band 9	Neutral density : T_{mean} = 10% over [550-850] nm (PAN)

Description of the macro pixel:



836nm	799nm	757nm
561nm	PAN	722nm
595nm	637nm	672nm