Spectral responsivity interpolation of silicon CCDs

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Abstract. An interpolation procedure for CCD responsivity that takes into account physical considerations about the pixel is presented. The procedure has been applied to the responsivity values of a CCD and the results are shown.

Introduction

After the radiometric calibration of any detector, it may be necessary to interpolate in order to estimate responsivity values between the calibration wavelengths. A typical spectral responsivity feature of a front illuminated CCD cannot be accurately approximated by a single mathematical function because of its shape. Then a different approach must be followed to interpolate.

The spectral responsivity has to be based on the absorption and charge collection in the pixels, therefore an interpolation procedure, based on estimating the pixels' reflectance and internal quantum efficiency, is proposed in this work. Such an interpolation allows to predict responsivity changes in changing the parameters and vice versa. Its feasibility has been proved by applying it to experimental responsivity values of a CCD calibrated in our laboratory, whose results have been presented in previous works.[1,2]

Pixel responsivity

According to the international vocabulary of Illumination[3], the responsivity of a pixel (R) is the ratio between the response and the radiant exposure. So, R can be written as:

$$R(\lambda) = \frac{\eta_i(\lambda)(1-\rho(\lambda))\lambda_0 A}{Khc} \qquad (1)$$

Where h is the Planck´s constant, c is the light´s velocity, K is the conversion factor e^-/counts, λ_0 is the vacuum wavelength, ρ is the pixel reflectance, A is the pixel sense area, and η_i is the pixel internal quantum efficiency. This last quantity can be expressed for a front-illuminated CCD as[4]:

$$\eta_i = \eta_{opt}\beta \exp(-X_{PSi}\alpha)[1-\exp(-W\alpha)] \qquad (2)$$

where α is the silicon absorption coefficient, W is the depletion region depth, X_{PSi} is the width of the polisilicon layer, η_{opt} is the optical efficiency (that accounts the responsivity variation due to the incidence angle variation), and β is a factor that represents the non ideality of the charge collection and charge transfer processes, whose value is close to 1.

Interpolation procedure

The interpolation procedure consists of fitting equation 1 to the experimental spectral responsivity values, using equation 2 for the internal quantum efficiency. The variables involved in the fitting would be A, K, ρ, η_{opt}, β, X_{PSi} and W. The absorption coefficient and physical constants values can be obtained from the literature. η_{opt} can be taken as unity for the purpose of this work. In a first approach and to simplify the fitting, the discussion can be restricted to scientific CCD, then, A can be considered as a constant for all the pixels and a typical value given by the CCD manufacturer can be taken for it as well as for K. β can also be assumed to be unity for this kind of CCD and therefore the fitting variables are reduced to ρ, X_{PSi} and W. X_{PSi} and W can be assumed to be equal for all the pixels, but the reflectance may change from one to another in addition of being a function of wavelength, radiation solid angle, polarization, etc.

Since ρ is difficult to measure because the pixels are very small and difficult to predict because the CCD is a very complex system from the reflectance point of view, an iterative method can be used to obtain physically significant reflectance values:

1. From typical values for W and X_{PSi} spectral quantum efficiency values can be calculated for every pixel (eq. 2) at the wavelengths the responsivity is known.
2. From those values, spectral reflectance can be calculated from equation 1. If those values are physically significant, they are taken as the actual reflectance values, if not, new values are calculated from a different set of W and X_{PSi}.

To conclude the interpolation of the responsivity, it is necessary to interpolate the reflectance values obtained previously. Unlike the case of a single detector, the CCD responsivity interpolation has to take into account the large amount of pixels involved. So it is important for the interpolation procedure to be simple and because of that a linear interpolation of ρ is done.

The result of this interpolation procedure is a responsivity expression for each pixel, based on pixel's the physical parameters.

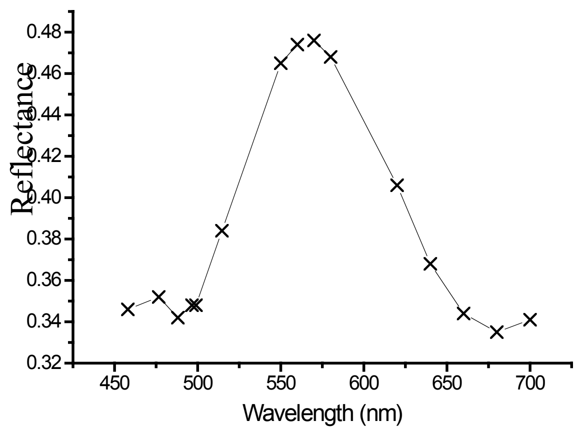

Figure 1: Calculated ρ for the average responsivity of a CCD.

Results

The procedure described before has been applied to a CCD calibrated in our laboratory. Choosing $W = 1.5$ µm and $X_{PSi} = 0.175$ µm, the resulting average ρ is shown in Figure 1. The reflectance stands between 0.34 and 0.48 (physically significant values), and has a maximum at around 570 nm. This figure also shows the linear interpolation. Notice that the maximum (the more conflictive curvature point) is well-sampled, so the linear interpolation is reliable.

The interpolation result for the average responsivity is shown in Figure 2. Notice that, although the reflectance was linearly interpolated, the responsivity presents curvatures, given by the typical shape of the internal quantum efficiency function.

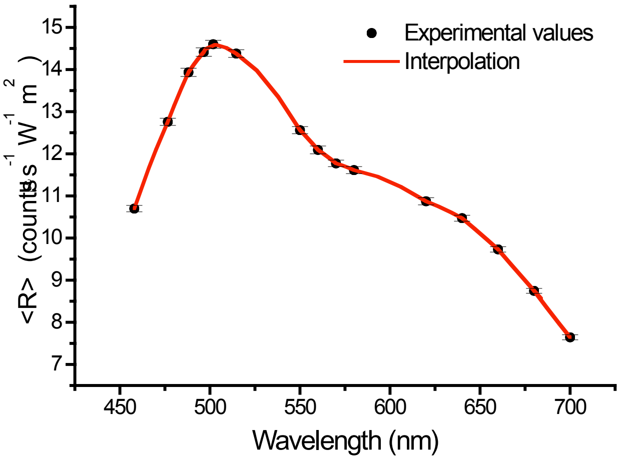

Figure 2: Average experimental responsivity of a CCD and its interpolation.

Conclusions

An interpolation procedure for the spectral responsivity of a CCD based on an estimate of the internal quantum efficiency and the reflectance of its pixels has been developed. This procedure has been applied to a CCD and the results obtained have been shown. Responsivity functions have been calculated for each pixel, being the only difference among them the pixel spectral reflectance values.

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References

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