Linearization of Silicon-CCD-Sensors for Multispectral Imaging

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Abstract. *Multispectral imaging technologies have a steady increase on importance in the last decades, because of the computing power which can be used for the processing of the data. There are three different types of multi spectral imaging systems: push broom systems, whisk broom systems an filtered systems. All these principles are equipped with different kind of detectors depending on the spectral working range. The detectors have a specific spectral response which depends on the detector material. Mostly it is has a peak on a special spectral range and decreasingly fading out at the end of the spectral working range. This leads to a loss of dynamic range on these edges. The approach, given here delivers possibilities to avoid this dynamic loss by different methods of linearization for a silicon CCD sensor.*

Keywords: Multispectral Imaging, Linearization of Silicon Sensors, Spectral Measurements,

1. Introduction

The analysis of colour space is only possible to a certain limit with an ordinary colour camera [1]. The technical function principle of ordinary RGB cameras with a maximum of three colour channels can dissolve only a limited range in the colour space and loose spectral image information. Narrow wavelength bands in consideration of a broad overall spectrum are particularly difficult or impossible to mapping with a sensor of nonadjustable colour channels. The comparatively large sensitivity of the three individual colour channels results to lose some spectral information. It is acceptable for most colour imaging applications and a cost effective solution. A multispectral camera operates with several colour channels and reconstructs a complete spectrum with specific numerical methods [2]. One important precondition is broadband illumination and precise knowledge of the spectral properties of the whole multispectral camera and illumination system. Filter wheel cameras present an effective and affordable alternative in multispectral image acquisition. Their modular and versatile structure, as well as the consistent enhancements in filter and sensor technology offer many pros for use of these systems. Depending on the procedure of filter setting, it is possible to set a characteristic calibration set for every filter for the specific wavelength. This leads to the possibility to correct the characteristic of the sensor.
For multispectral imaging as well as for high dynamic colour imaging, silicon sensors are used for the most industrial applications. The motivation for the presented work is the use of these sensors for multispectral imaging, enhancing the quality of information on the supported spectral range of the integrated image sensor.

2. Spectral Sensitivity of Silicon CCD Sensors

As mentioned in the introduction many of industrial imaging applications using silicon based image sensors for capturing the visible and the near infrared range of light. A typical spectral characteristic of a silicon based imager is depicted in Fig. 1 beside the characteristic of the penetration depth of different wavelength in silicon. The graph shows an intensity maximum at 500 nm with a cut at 400nm and a slightly decrease in the infrared region down to a relative sensitivity of 5% at 1000nm.

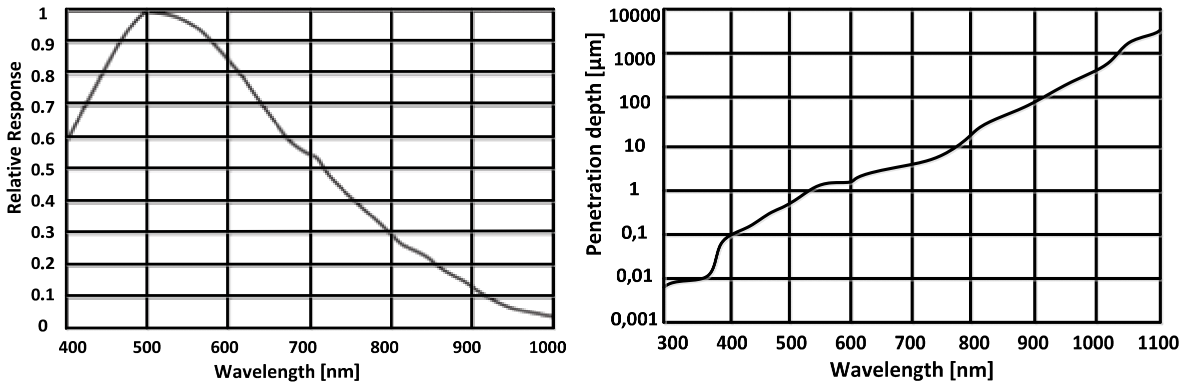

Fig. 1. Spectral response CCD Sensor ICX 424 AL (left), wavelength dependent penetration depth in silicon (right)[3].

Reason therefore is the wavelength dependent penetration depth of light following equation (1) where $\Phi_{e\lambda}(z,\lambda)$ is the spectral radiant flux into the silicon, z the penetration depth and $\alpha(\lambda)$ the absorption coefficient.

$$\Phi_{e\lambda}(z,\lambda) = \Phi_{e\lambda}(0,\lambda)\ e^{-\alpha(\lambda)z} \qquad (1)$$

The Graph on the right side in Fig. 4 illustrates the characteristic penetration depth of silicon. According to the equation (1) short wave light cannot penetrate very deep into the silicon. This leads to a recombination of photons on the surface of the silicon. The electric charges could not reach the potential well of the CCD pixel. That leads to a bad sensitivity into the ultraviolet range, as depicted on the left. The long wave light leads to an opposite effect. The photons can penetrate into the silicon very deep, the longer the wavelength the deeper the penetration depth. Depending on the depth, generation of electric charges may be under the potential well and the electric charges can flow into another pixel region. This effect can lead to a blurred image [4] especially on sensors with small pixels. Otherwise back illuminated sensors using this characteristic of silicon improve the infrared response of the sensor. These effects leading to typical spectral response of silicon (Fig.1. left).

3. Measurment Setup – The Multi Spectral Imager

For the measurement of the spectral behaviour of the CCD silicon sensor as well as for the test system for the linearization methods and the cause to spectral imaging, the multi spectral imager depicted in figure 2 was used. The multispectral imager system [5] is characterized by up to 12 exchangeable band-pass-filters in a wheel and samples a colour spectrum from 375 nm to 975 nm. The spectral resolution is limited by the band-pass-filters and the associated bandwidth of 50 nm or 10 nm. For this purpose several adjustment options are integrated in filter-wheel. Furthermore the spectral channels can be controlled individually for various imaging tasks. An integrated Field Programmable Gate Array (FPGA) offers efficient pre-processing capabilities.

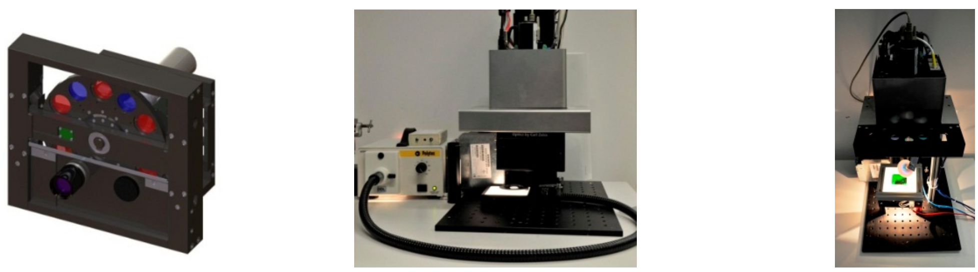

Fig. 2. 3D- model of the Multi-Spectral-Imager (left), measurement setup with the Multi-Spectral-Imager and mirror lens (middle), measurement setup with the Multi-Spectral-Imager and normal lens (right).

4. Linarization – Different Approaches

According to chapter 2 it is a big advantage to correct these characteristic of silicon for spectral measurements, getting a better signal to noise ratio in the infrared and ultraviolet spectral range. Therefore in the following three different possibilities were investigated. For the linearization concerning exposure time based and gain based linearization, a stabilized halogen bulb was used, with the assumption of a well-balanced distribution of light. For these two approaches a system integrated Field Programmable Gate Array detects the position of the filter-wheel and load the correction set for the actual filter. Fig. 3 contain

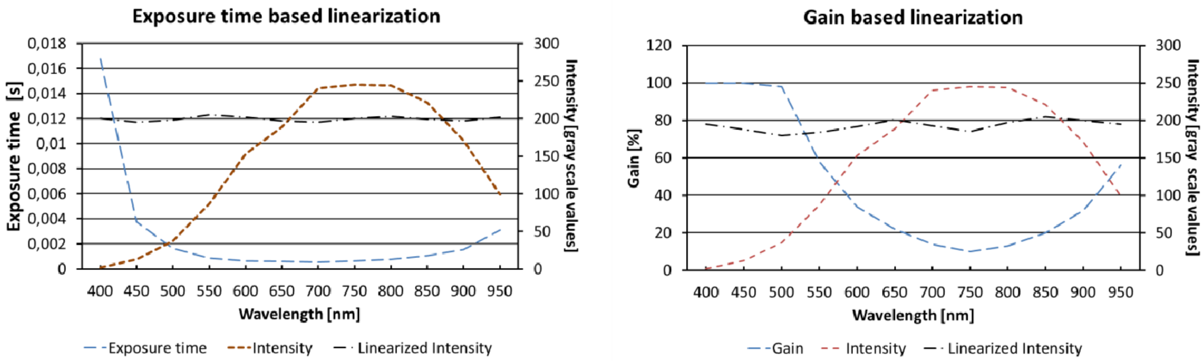

Fig. 3. Exposure time based linearization for the silicon sensor in the multispectral imager (left), Gain based linearization for the silicon sensor in the multispectral imager (right). The blue long dashed lines depicting the correction function (gain/exposure time) for the silicon sensor, the brown shorter dashed lines depicting the sensor modulation amplitude without correction and the black dotted-dashed line the corrected sensor modulation amplitude.

the results of these linearization methods. The target intensity was adjusted to 80% of the sensor modulation amplitude. The intensity values are averaged over the whole image. As depicted in Fig. 3 the exposure variation offers a more stable intensity and more modulation power reserves for low light application beginning with the 450 nm band in comparison to the gain variation method. To get even more modulation power reserves for the sensor, a light mixing method was analyzed. Therefore two halogen bulbs, one filtered with a BG3 filter and one unfiltered, were combined together to control the infrared light independent to the visible light range. Additional a halogen bulb and infrared LED (850nm, 950nm) were controlled independent in the backlight. Fig. 4 illustrating the results of this investigation.

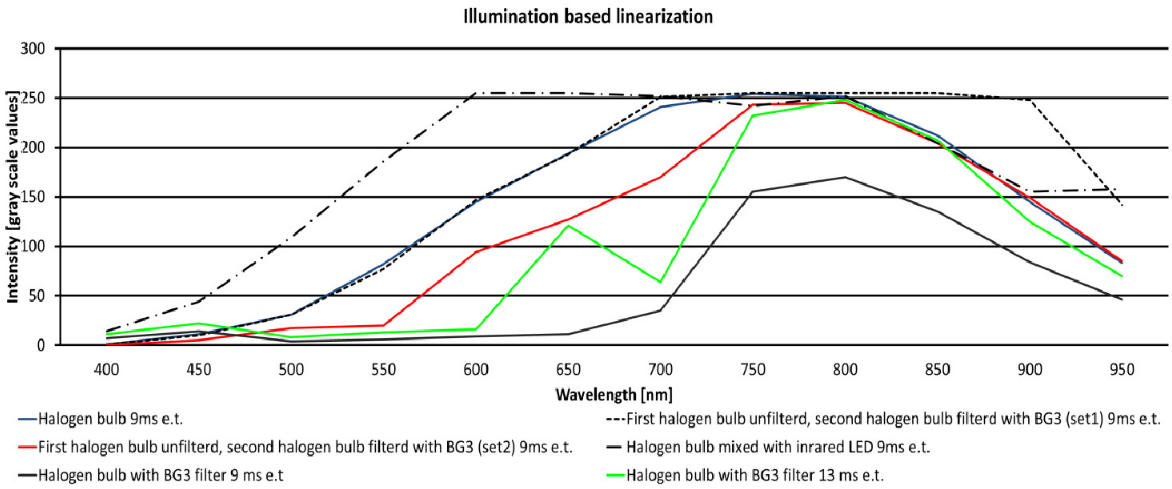

Fig. 4. Light mixing results, analysed in special backlight with different sources and filters (e.t. - equals exposure time)

Best results for an independent light control linearizing the sensor delivers the LED halogen bulb configuration. The halogen bulb mix does not work well because the infrared light of the unfiltered bulb and filtered bulb amplifying together. To get an increase in the ultraviolet and the visible light range, three or better four colour filters for the illumination are necessary. In case of an LED solution even more bands are needed to get a well-balanced light source.

5. Results and Discussion

After the investigation presented in chapter 4 the final method for the MSI is the linearization varying the exposure time at that state of investigation. In case of a better filter characteristic for the illumination, this approach is also well suited for applications in spectral imaging. To gain the visibility and the impact of the linearized MSI two targets were captured in all spectral bands and shown in the visible bands and in the infrared bands. Without the linearization an image processing in the IR bands is impossible.

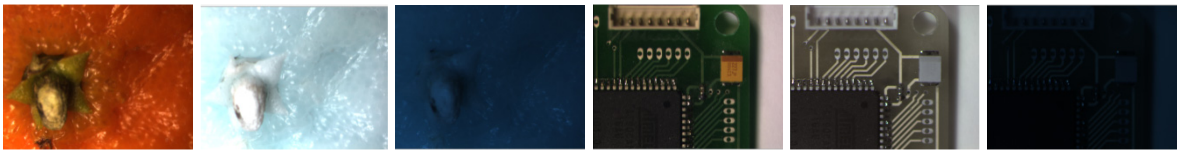

Fig. 5. Result pictures as an RGB mapping for spectral bands (450nm, 550nm, 600nm) and IR RGB mapping (850nm,900nm,950nm) with and without exposure time based linearization in the IR bands, beginning from the left **a.)** Mandarin RGB linearized **b.)** Mandarin IR RGB linearized **c.)** Mandarin IR RGB non-linearized, **d.)** Printed circuit board linearized **e.)** Printed circuit board IR RGB linearized **f.)** Printed circuit board IR RGB non-linearized.

Especially the characterization of biological objects, here a mandarin with the information in the IR band (Fig. 5/b.), is useless without the corrected spectral response (Fig. 5/c.). The second application shows a printed circuit board where the wires could be clearly uncovered in the IR bands with the linearization method (Fig. 5/e.) and colour features can be measured in the RGB bands (Fig. 5/d). Image processing in the uncorrected date (Fig. 5/f.) is hardly possible with the image dynamics.

Acknowledgements

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References

[1] F. Konig and P. Herzog, “On the limitations of metameric Imaging”, Proceedings of IS&T PICS, 1999, pp. 163-168.

[2] M. Yamaguchi, H. Haneishi, and N. Ohyama, “Beyond Red-Green-Blue (RGB): Spectrum-based color imaging technology,” J. Imag. Sci. Technol., vol. 52, no. 1, pp. 010 201-1–010 201-15, Jan. 2008.

[3] E. D. Palik, “ Handbook of Optical Constants of Solids”, Academic Press, Sant Diego 1998.

[4] U. Krüger, “Ausgewählte Aspekte der ortsaufgelösten Erfassung stationärer Licht- und Farbverteilungen”, Fachgebiet Lichttechnik Publikationsreighe 6, Ilmenau 2004.

[5] M. Preißler, M. Rosenberger, M. Correns, M. Schellhorn and G. Linss, „Investigation on a modular high speed multispectral camera“,Proceedings of the 20th IMEKO TC2 Symposium on Photonics in Measurement : May 16 - 18, 2011, [Linz Austria], pp.59-62, Aachen : Shaker, 2011.