

Camera Operational Characterisation: Stingray F-033 and Imaging Source USB DFK 23U274

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Abstract

The aim of this report is to characterise two CCD cameras and study their linear response to optical illumination, their dynamic range and background noise. Two different cameras, one a monochrome Stingray and the other a colour IS USBcam are examined.

For both cameras the proportionality between incident light and output signal is shown and the dynamic range of the cameras is found, the Stingray at 14 bit, is found to have the largest dynamic range. It is also found that the IS USBcam has a significant increase in background counts due to heating up of the chip during measurements.

1 Introduction

The following report details properties and characteristics of two CCD cameras; a greyscale Stingray¹ at 12 bit and 14 bit and a colour Imaging Source (IS) USBcam² at 8 bit and 16 bit. The cameras are tested to study their linearity, dynamic range and background noise.

1.1 Charge Coupled Devices

The cameras studied are both CCDs. These work by capturing an analogue signal and outputting a digital signal. Photons are incident on the CCD where, if they have sufficient energy, they cause electrons to move from the valence band into the conduction band. In the conduction band they are stored into the potential well of each individual pixel. [1] This charge is then turned into a voltage so it can be measured and digitalised by the Analogue Digital Converter which gives out a signal or digital number, N . The ADC range is defined as the number of levels each voltage can be assigned to. [2] Grayscale digital images have only one channel, whilst coloured images have three channels (red, green and blue) which combined reproduce an array of colours. In CCDs the RGB filters are arranged according to the Bayer filter mosaic. This pattern is 50% green, 25% blue and 25% red. [3]

¹S/N 285897572

²S/N 20510217

1.2 Linearity, dynamic range and background noise

To characterise the cameras three properties are tested: linearity, dynamic range and background noise. In an ideal CCD the output signal should be proportional to that of the input signal. For a real CCD the output is ideally linearly proportional to the amount of light incident on the sensor. The dynamic range of the CCD is the ability of the CCD to distinguish different levels of light. As dynamic range is increased, the ability to measure the brightest and dimmest intensities is improved. The effective dynamic range is given by

$$DR = \frac{I_{max}}{I_{SNR=1}} \quad (1)$$

which is the ratio of maximum non-saturated light intensity, I_{max} , to the light intensity at signal-to-noise ratio of 1, $I_{SNR=1}$. [4]

The background noise is due to a combination of sources in the CCD such as readout noise from the chip and dark current generated within it. The readout noise is caused by random fluctuations in the readout amplifier which does not always measure the same number of electrons in every pixel; this value is similar for every shot regardless of the integration time. The dark current is a small electric current which flows through the CCD even when no photons are incident on it. This is mostly temperature dependent and becomes dominant at large exposure times due to the random generation of electron-hole pairs in the depletion region.

2 Method

Camera	Manufacturer	Active pixels	Sensor size (mm)	Pixel size (μm)
Stingray F-033	Allied Vision	659 x 494	7.48 x 6.15	9.9 x 9.9
USB DFK 23U274	Imaging Source	1600 x 1200	8.5 x 6.8	4.4 x 4.4

Table 1: Specifications of the cameras tested [5] [6]

Table 1 shows the specifications of the cameras for better comparison.

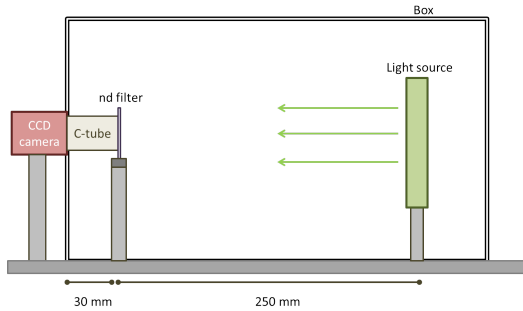


Figure 1: Experimental set up

The camera to be tested is placed in a light tight box with the inside walls covered with black tin foil to prevent any light being reflected off the walls. A uniform green light is shone onto the CCD by a 7 x 7 cm green light source. In front of the camera a 5 x 5 cm neutral density (nd) filter is placed to vary the light intensity incident on the CCD by using different optical densities.

To avoid any unfiltered light, c-tube is attached in between the camera and the filter. The box is made light tight by sealing the top and sides with black tape and attached to a bread board using black tape.

The optical densities used are 0.1, 0.3, 0.5, 0.7 and 1 to 5 in steps of 0.5. At each optical density 6 pictures are taken at an exposure time of 0.05 seconds and 0 gain. Using ImageJ, the mean number of counts and standard deviation is found for the most uniform region of the images.

The same method is applied to both cameras. For the Stingray camera this is done at 12bit and 14bit and for the IS Blue USBcam at 8bit and 16bit. The RGB images are split into three different channels using a MATLAB program before being analysed using ImageJ.

3 Results and discussion

3.1 Background noise

First the background noise of the cameras is characterised. The camera is shielded from light and all the room lights are turned off. The camera is covered with a black plastic lid. Several images are taken to measure the background noise caused by any other sources of light and the readout noise of the chip. This is done before and after taking a series of images.

Table 2 shows the values of background noise found for the cameras before and after using them. The Stingray camera does not show any change in background noise for exposure time of 0.05 s. However, the IS USBcam shows a significant increase in background counts.

Figure 2 shows the background counts vs time using the IS USBcam in minutes. Background counts were taken be-

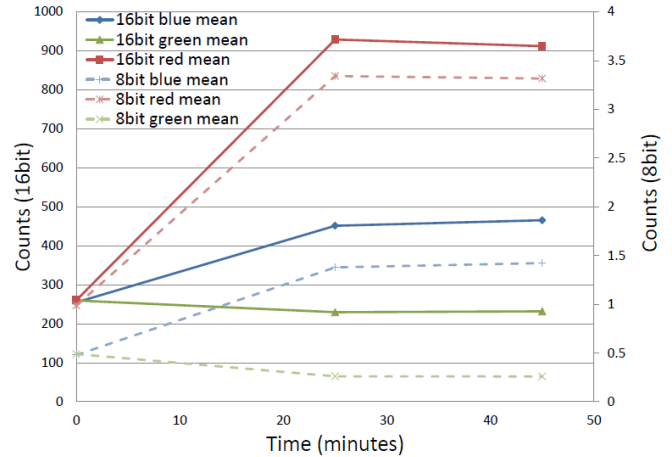


Figure 2: Background counts vs time, 16bit 8bit (exp t=0.05s) for IS USBcam

Camera	Background noise before use (counts)			Background noise after use (counts)		
Stingray 12bit	4			4		
Stingray 14bit	17			17		
	R	G	B	G	B	
IS USBcam 8bit	0.52	0.49	0.4	3.34	0.26	1.42
IS USBcam 16bit	260	259	254	912	231	465

Table 2: Readout noise before and after using the camera

fore, after and halfway through taking the linearity test pictures. It is clear that as the camera is used, it heats up, creating dark current within the chip, thus the background counts increase after time. It is also evident that the red channel has a larger drift in counts than the other channels. Green remains relatively constant but blue and red rise. This behaviour is observed at both 16 and 8 bit.

With further study, the dependence of background counts on time could be studied by taking background readings in between more pictures, for example in between every nd filter tested.

3.2 Linearity

To find the linearity of the cameras the mean counts were plotted with respect to incident light intensity. The nd filters were changed from lower optical density to higher op-

tical density changing the intensity of light incident on the chip, I given by

$$I = \frac{1}{10^{OD}} \quad (2)$$

where OD is the optical density of the nd filters. [7] Figure 3 shows the linearity plot for the Stingray camera at 12bit and 14bit ADC. There is a clear linear proportionality between incident light and output signal below saturation levels. The standard deviation of the images is small compared to the signal, indicating the images are relatively flat and the pixels in the chip behave in a roughly uniform manner. From the linearity it can be noted that the camera can be used over a range of approximately 3 orders of magnitude.

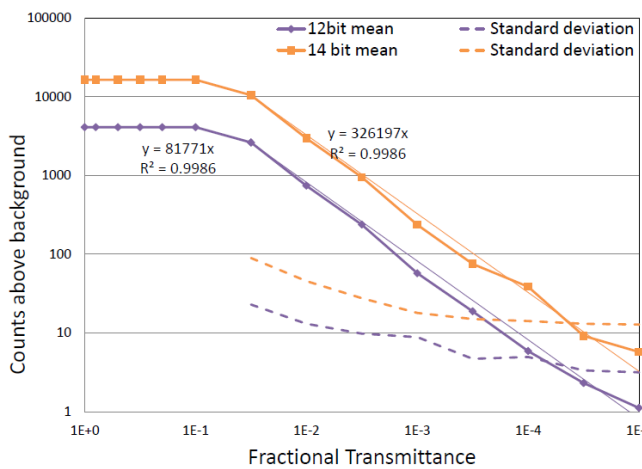


Figure 3: Linearity plot of mean counts and standard deviation vs fractional transmittance of Stingray at 12bit and 14bit

The overall response of the camera at 12bit is very similar to that at 14bit. The linearity of counts vs. fractional transmittance at both levels is the same (0.9986) which indicates the camera has the same linear response to incident light. Moreover, the standard deviation curve does not change much between the two either. This indicates the camera is limited by the chip and not the convertor as there is no actual benefit from using the 12bit or 14bit ADC.

Figure 4 and Figure 5 show the linearity plot for the IS USBcam at 8bit and 16bit respectively. Similar to the Stingray there is a clear proportionality between fractional transmittance and mean counts below saturation levels. Again, at both levels the standard deviation is small compared to the signal, thus images are relatively flat and pixels behave uniformly.

The camera can be used for light intensities in a range of 3 orders of magnitude for the blue and green channel and around 2.5 orders of magnitude for the red channel. As expected the camera behaves in similar manner at 8bit and 16bit. The chip also has a more uniform response at green

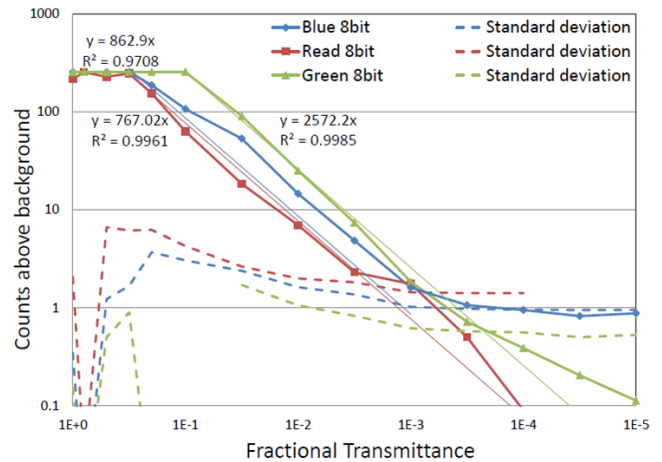


Figure 4: Linearity plot of mean counts and standard deviation vs fractional transmittance of IS USBcam @8bit

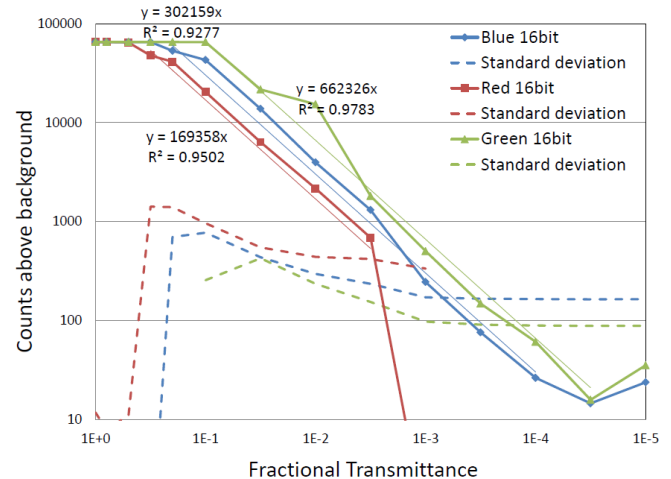


Figure 5: Linearity plot of mean counts and standard deviation vs fractional transmittance of IS USBcam @16bit

channels than red or blue, probably because the incident light is green.

For the 16 bit there is a large decrease of counts in the red channel at 10^{-3} fractional transmittance. The background subtraction introduces an uncertainty due to the behaviour of background counts not being characterised. For this same reason the linearity plot for the IS USBcam overall is limited. From Figure 2, it can be seen that there is a big jump from 0 minutes to 25 minutes, however the behaviour of this growth is unknown due to the lack of data taken in between. This could be improved by taking a background reading in between every OD to see better the behaviour of the dark current.

3.3 Dynamic Range

The dynamic range is calculated from Equation (1). To illustrate this, the signal-to-noise ratio (SNR) is plotted with re-

spect to mean counts. The SNR is given by

$$\frac{N_{\mu}}{N_{\sigma}} \quad (3)$$

where N_{μ} is the mean number of counts and N_{σ} is the standard deviation of the counts. [4]

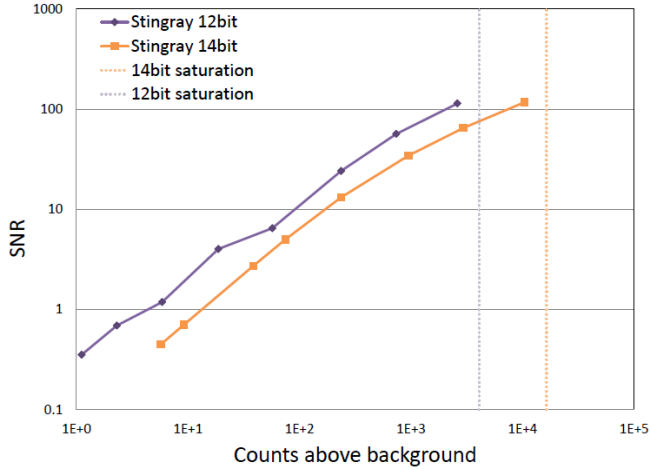


Figure 6: SNR vs mean counts of Stingray at 12bit and 14bit

Figure 6 shows the plot of signal-to-noise ratio with respect to mean counts for the Stingray at 12bit and 14bit. Both lines show a linear proportionality up to $SNR=100$. This is also the maximum achievable signal before hitting saturation levels. The signal-to-noise ratio does not fall further below $SNR=1$ for either cases. Similar to the linearity plot, the response of the chip at 12bit and 14bit is the same, indicating again there is not much difference between using the camera at 12bit or 14bit.

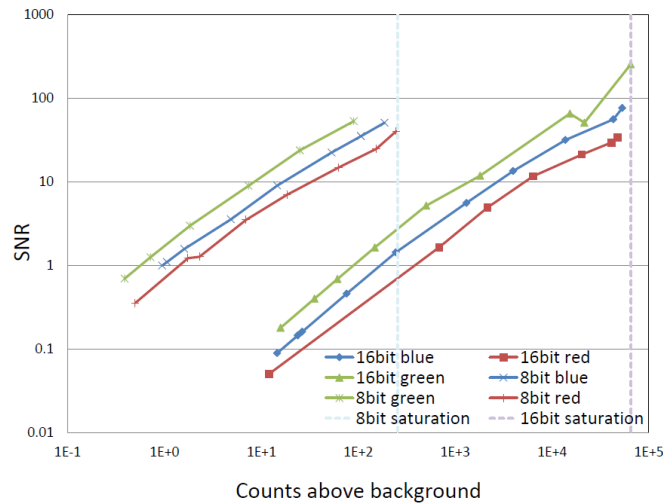


Figure 7: SNR vs mean counts of IS USBcam at 8bit and 16bit

Figure 7 shows the plot of signal-to-noise ratio with respect to mean counts for the IS USBcam at 8bit and 16bit

for three different channels. The overall response of the chip is very similar for both levels. Each colour channel behaves similarly regardless of whether it is at 8 bit or 16 bit.

Table 3 shows the dynamic ranges of the cameras. The values of the dynamic range of the IS USBcam are not particularly representative because of the arbitrary background subtraction due to temperature drift. The background subtraction is arbitrary due to the change in background counts over the time using the camera. Therefore, for the first half of data the background subtracted was that found before using the camera and for the second half, the background subtracted was the one halfway through. The green channel has a much higher dynamic range than the other colours because the light used is green so the CCD captures more green counts at lower transmittance than other channels. Also the background counts for green channel stay roughly constant regardless of time using the camera.

Camera	Dynamic Range		
Stingray 12bit	122		
Stingray 14bit	127		
	R	G	B
IS USBcam 8bit	34	53	49
IS USBcam 16bit	29	65	33

Table 3: Dynamic range of tested cameras

4 Conclusion

In conclusion the Stingray camera is a better choice for a general purpose CCD than the IS USBcam. The dynamic range of the Stingray is much higher than that of the IS USBcam at any channel. Moreover the main limitation of the IS USBcam is the large creation of dark current with respect to time using the camera. This is a significant limitation specially because it shows a very different response of the three channels as the green channel almost does not change whilst the blue and red channel increase in counts, red being the most significant.

5 Acknowledgments

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