Andor CCD Camera Characterization

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Abstract

This paper details the performance characteristics of a 2048x512 pixel array charge-coupled device (CCD) camera, model DU440A-BV, manufactured by Andor Technology for applications in spectroscopy and imaging. The back-illuminated CCD chip is the CCD42-10bi manufactured by Marconi EEV. Among the characteristics studied in a controlled laboratory environment are: read noise, dark current, linearity, blooming, and charge transfer efficiency. The CCD was set to a pixel readout speed of 50kHz and thermoelectrically cooled to -40°C. Read noise is determined to be ~4e^-s. Dark current hovered just below detection, the response was extremely linear for non-extreme exposure durations (>99%), the peak charge storage was determined to be about 120,000 e^-s, and charge transfer efficiency was found to have a lower limit of 99%.

Introduction

The following CCD characteristics are studied and determined experimentally at a fixed temperature of -40°C and readout speed of 50kHz:

1. The read noise, which originates from the amplifier and switch on the output of the CCD, is measured in digital numbers (DNs) and is converted to units of electrons via the method outlined by Janesick, Klaasen, and Elliot (Optical Engineering 26(10). 972. 1987).
2. An attempt is made to measure dark current, which is a source of noise originating from thermally generated "hits" on the CCD detector, as a function of time. The results (from 1 and 2) can be useful in distinguishing noise from signal when the chip is cooled to lower temperatures.
3. The linearity is measured by taking exposures of different lengths of time in both a high and low-level light environment. The speed of the shutter mechanism is also examined for short (<1 sec.) exposures.
4. Blooming, which is caused by electropotential "bins" overflowing with electrons, is measured as a function of exposure time. The length of the trail and saturation are both detailed.
5. An attempt is made to measure the charge transfer efficiency (CTE), a measure of the CCD's efficacy in moving charge across the silicon, as percentage of DNs.
6. Throughout the experiment bias frames and dark exposures are taken as precaution to prevent unpredictable variations in the response of the equipment from skewing results.

The results of these measures are important in establishing the operational limits of the detector. The results are also compared to the manufacturers' cited specifications, namely for Andor's camera and the Marconi EEV CCD chip.

Procedure

1. The read noise was measured with a series of 10 bias frames in a dark room environment. More specifically, overhead lights were off, other sources of light were removed (from the computer monitor), the lens cap was in place, and a metal bucket ("hood") was placed over the entire camera assembly. Theoretically, a low-light environment shouldn't be absolutely necessary, but short (3-30 sec.) dark exposures did indicate that there was some degree of light leak with the overhead lights on, the hood off, and lens cap on. It is most likely that light leaks through the body of the camera (perhaps around the heat vent at the top which would explain the very slight top-bottom gradients in the dark exposures).
2. The dark exposures to measure dark current were also taken in a dark room environment.
3. The linearity of the camera was measured in a relatively low-light environment to allow for a good spread in exposure duration. The overhead lights were turned off, the monitor was directed towards the wall to diffuse the light and the brightness of the monitor was kept constant throughout. Diffuse light from the adjacent computer lab also leaked over the wall in addition to light from underneath the door. A white piece of paper was imaged and the lens was focused to infinity while with the f-stop remained set at 22. This setup allowed for exposure times from 1 to ~200 seconds before saturation occurred. Very short exposure (<1 sec.) were also taken in this light environment to determine the speed of the shutter. A lower light environment was created by turning off the monitor. The only light, then, that leaked in was from the computer lab and from underneath the door. The same piece of paper was imaged and exposures were taken up to 300 seconds.
4. Blooming was measured by imaging a pinhole on a light-sealed box that enclosed an incandescent bulb attached to a tone generator, which allowed for frequency (and therefore brightness) control. The pinhole was brought into focus, the f-stop set to 22, the frequency on the tone generator brought to 25 Hz, and a constant low-light environment was maintained throughout.
5. In measuring the CTE, the same conditions were used as in measuring the read noise. The lens cap was on, hood on, and overhead lights off.
6. A pair of bias frames and flat frames were taken to determine the gain and, from that, a conversion factor between DNs and number of electrons (e^-s). The flat frames were taken in a relatively low light environment with a piece of evenly illuminated paper that was placed a few centimeters away from the lens. The camera was focused to infinity and the f-stop set to 22. The bias frames were taken in dark room conditions.

Observations and Results

By assuming a Poission distribution of noise conversion from DNs to e^-s can be found experimentally through the use of a pair of bias frames and flat frames as outlined in the lab handout.

The analysis performed in IDL returned the following results (error/sig. figures are not considered for values used in later calculations):
Mean level of signal in DNs: S_{DN}=1309
Total variation in DNs: $\sigma_{tot,DN}$=25.717
Read noise (only from 2 biases): $\sigma_{R,DN}$=2.1708279
Poission noise (DNs): $\sigma_{Poission,DN}$=25.625
Gain (DNs/e^-s): g=0.5
Conversion factor (e^-s/DNs): 2.

This result is used in converting DNs to e^-s in later measurements.

1. Read Noise

The standard deviation was measured in two ways. An 11x11 pixel region centered on (1395,271) was chosen because it lacked any structure that might arise from the manufacturing process of the CCD chip. The standard deviation was also measured for the entire frame.

Bias Number	StdDev at (1395,271) 11x11 (DNs)	StdDev of entire frame (DNs)
1	2.153	2.046
2	2.074	2.044
3	2.082	2.120
4	2.153	2.800
5	2.193	2.064
6	2.228	2.308
7	2.019	2.099
8	2.130	2.072
9	2.039	2.085
10	2.163	2.256
Mean and Error (from StdDev)	2.1±0.1	2.1±0.2

Both values seemed to converge to ~2.1 DNs. The standard deviation of the entire frame proved to be more uncertain which makes it a more conservative choice for an actual noise estimate.

In units of electrons the read noise is: 4.2±0.4 e^-s.
Andor doesn't specify the read noise for a readout speed of 50kHz, but it does provide "typical" values for noise of 3 e^-s (at 31kHz) and 10 e^-s (at 1MHz). A read noise of 4 electrons certainly doesn't fall outside their quoted specifications.

2. Dark Current

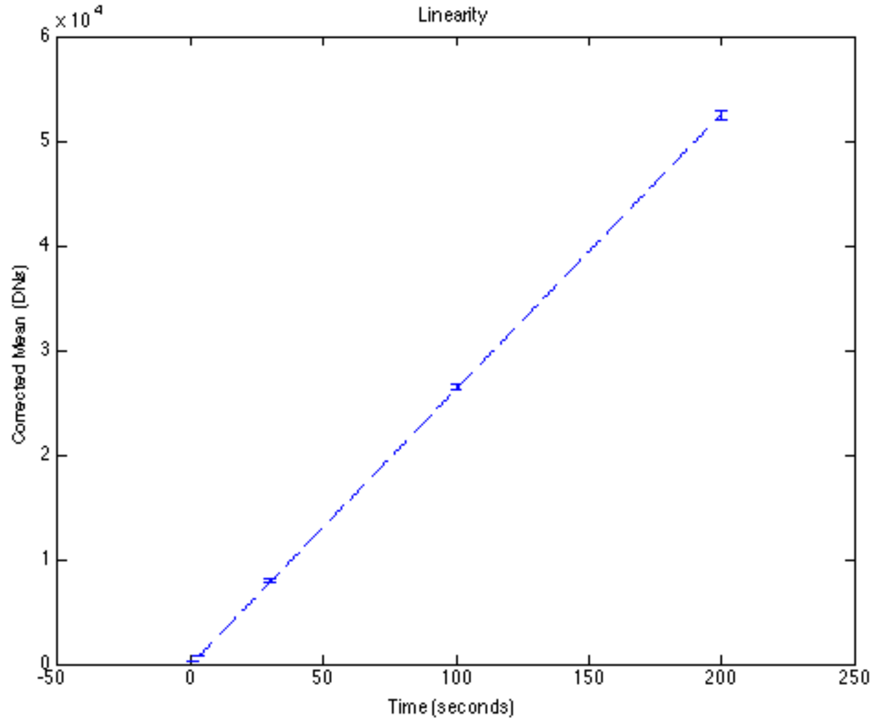
Exposure Duration (sec)	Mean of entire frame (DNs)	Mean of entire frame with offset correction (from Bias frames) (DNs)

10	316±3	-3±3
20	315±4	-3±4
40	312±6	-2±6
80	312±12	-3±12
160	312±21	-3±21
320	312±40	3±40

I was unable to detect any statistically significant measure of dark current. The classmates that I spoke to were also unable to measure dark current.
According to the manufacturer, at -40°C, dark current should be ~0.04 electrons/pixel/second. That means in 320 seconds, I should have measured an increase of about 13 electrons/pixel/second. In DNs this corresponds to about 6 DNs/pixel. I did measure an increase of around 6 DNs after taking into account bias drift, but that result could still be within the realm of randomness and shouldn't be taken as a very accurate measurement in and of itself.

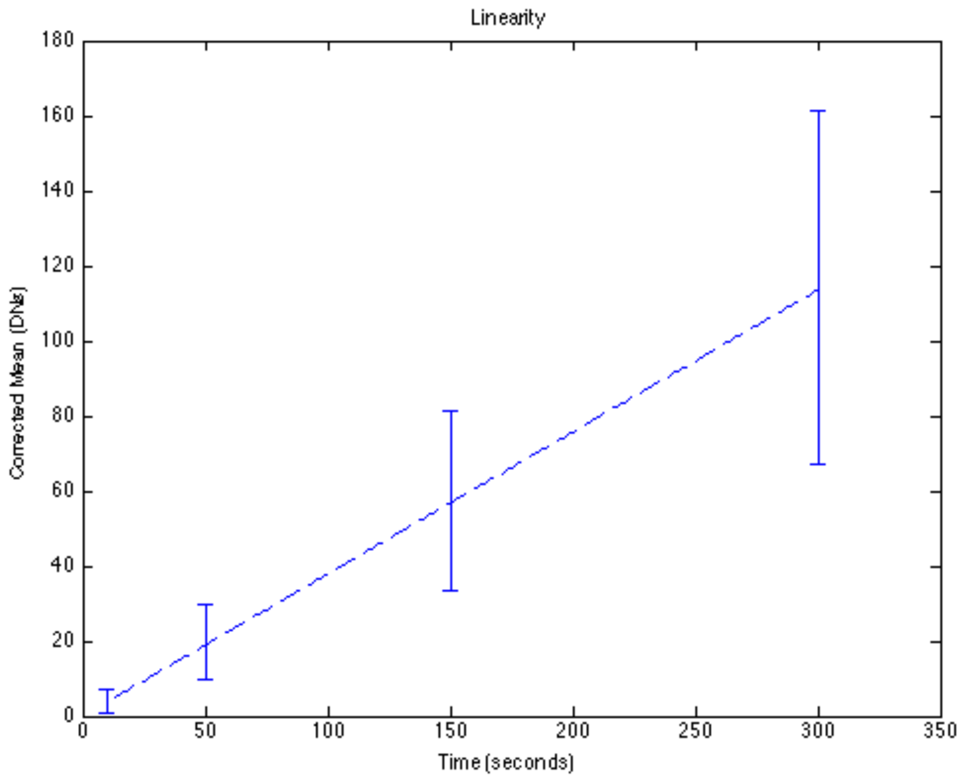
3. Linearity

Shorter Exposures in Higher light Environment (included light from monitor)
Five data points of corrected means in DNs (at 1, 3, 30, 100, and 200 sec.) are presented in graphical form with error bars that depict the RMS deviation in DNs. The DNs were gathered in all the following plots from an 11x11 pixels square centered at (999,324) because this region seemed to lack any discernible structure. A linear fit to the data is also plotted as the dotted line. The slope of the best-fit line was found to be 263 DNs/sec. The adjusted value of R^2 for this fit was >99.9%, which suggests a very good linear response that is well within the manufacturer's specifications.

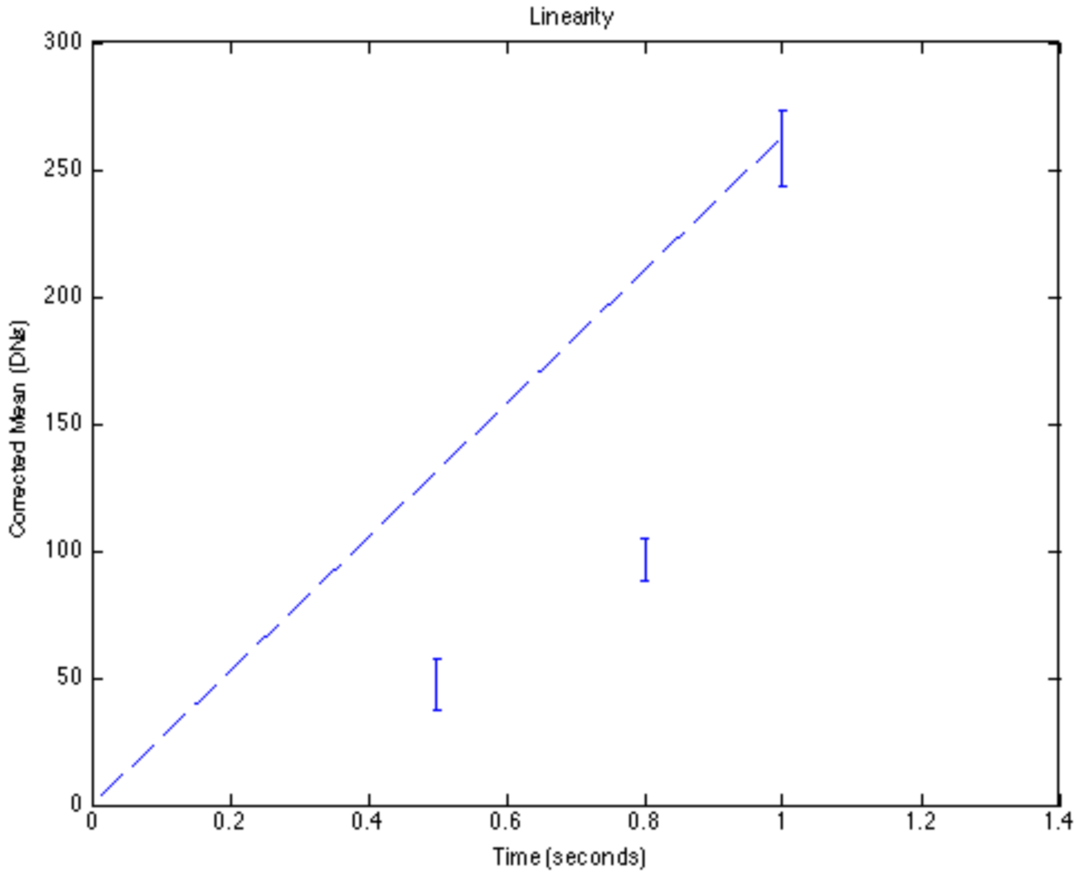


Longer Exposures in Low Light Environment (did not include light from monitor)
Four values of corrected mean (DNs) are presented at 10, 50, 150, and 300 seconds with error bars of RMS deviation. A linear fit is also included. The slope of this line was found to

be 0.38 DNs/sec.



Shutter Mechanism Analysis
Three short exposures were taken in the higher light environment to analyze the behavior of the shutter for exposures lasting less than 1 second. The same line that was plotted for the higher level light (with slope 263) above was plotted here. The values have also been corrected (levelled to zero).

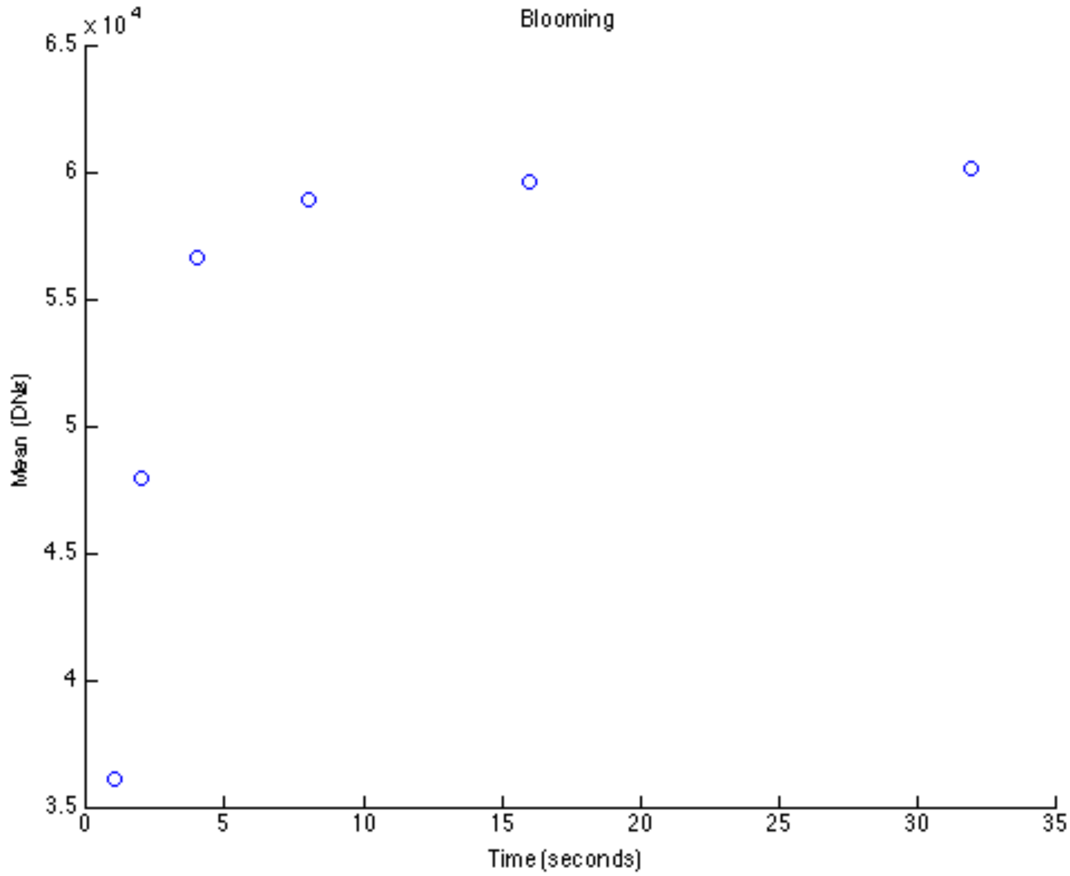


The shorter exposures seem to be too short, which indicates a slow shutter. The CCD hasn't gathered nearly as much light as would be expected. The error is significant for any exposure lasting less than a second.

4. Blooming

I was unable to generate peak numbers above ~61,500 DNs. Nevertheless, it was obvious that some form of physical saturation had occurred. Vertical streaks appeared first above the point source and eventually below the point source.

The following is a plot of the uncorrected means of an 11x11 box centered on the bright point as a function of exposure time. Error is not included and the mean is not adjusted because this graph is used solely for the purpose of demonstrating non-linearity.



Before saturation occurred, the central well was filled to a DN of ~58,000. In photoelectrons this value would correspond to ~120,000 e^-s. This suggests that beyond this value the CCD certainly shouldn't be expected to respond linearly. The CCD manufacturer states that "typical" peak charge storage is 100,000.

5. Charge Transfer Efficiency

In comparing the 2 300 second dark exposures only a few good (not "potato") cosmic ray hits (CRHs) were detected. The highest transfer efficiency I was able to measure was a serial CTE lower limit of 99%. I was only able to find one instance of a CRH that indicated any degree of imperfection in parallel CTE. The lower limit for parallel CTE measured (from only one data point) was also 99%.

The CCD manufacturer used x-ray photons of known energy to determine a parallel CTE of 99.9999% and a serial CTE of 99.9993%.

Conclusion

The purpose of this lab was to understand the operational limits of the CCD. In this endeavour the experiment was for the most part successful. The results support the specifications provided by the respective manufacturers and provide important limits that may be useful in future observation. The failure to detect dark current may be attributable to simply not having long enough dark exposures. There is certainly room for improvement in this area.

References

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