

AST2210 - Lab exercise: CCD

1 Introduction

In this project we will study the performance of a standard CCD, similar to those used in astronomical observations. In particular, the exercise will take you through the basics of operating a CCD cameras, recording data and analyzing the images afterwards. The current text describes how to do this in IDL, an interactive language commonly used in astronomical analysis, but you are free to use whatever programming language you prefer, as long as you know how to perform equivalent tasks in that language. In the report, pretend that you are the inventor of CCDs, and describe how these can be used for and revolutionize astronomical applications!

2 Camera usage

In the first exercise you will use a color Edmund Optics USB camera in a set-up with a white light lamp, a thin singlet lens and a microscope objective.

Connect the camera to the computer and start the 'camera viewer' program from the desktop. Start the camera by pressing 'mount camera', see figure 1. Start the white light lamp – you should now see an image of the white light source.

Exercise 1

Open 'histogram', 'value on horizontal line', and 'camera properties'. Experiment with the three settings as seen on figure 2. Describe what happens to the image when adjusting each of them and explain what you see.

Exercise 2

Change the focus position of the microscope objective. Describe what happens. Try to reach maximum counts for each color (with fixed exposure time) and note down the values. Is the maximum counts the same for each color?

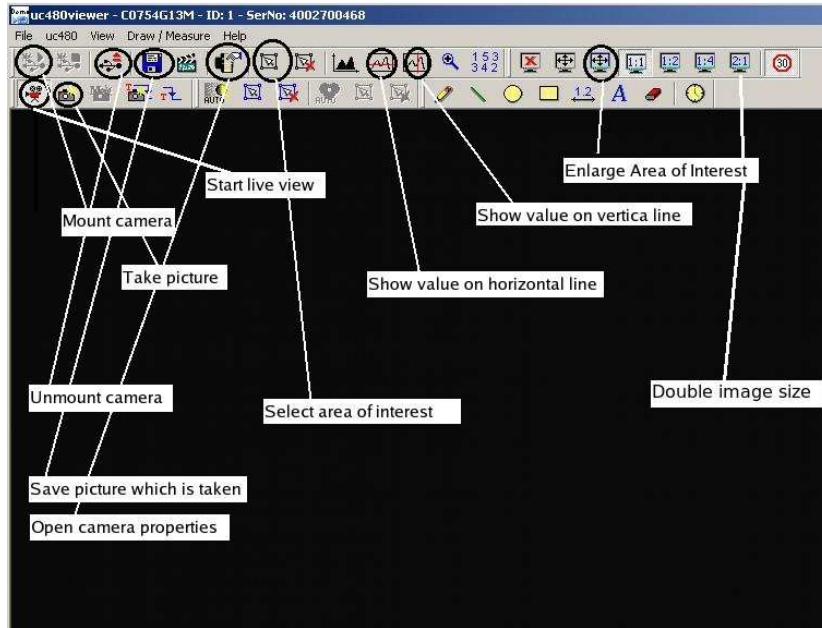


Figure 1: Graphical User Interface for the camera viewer program.

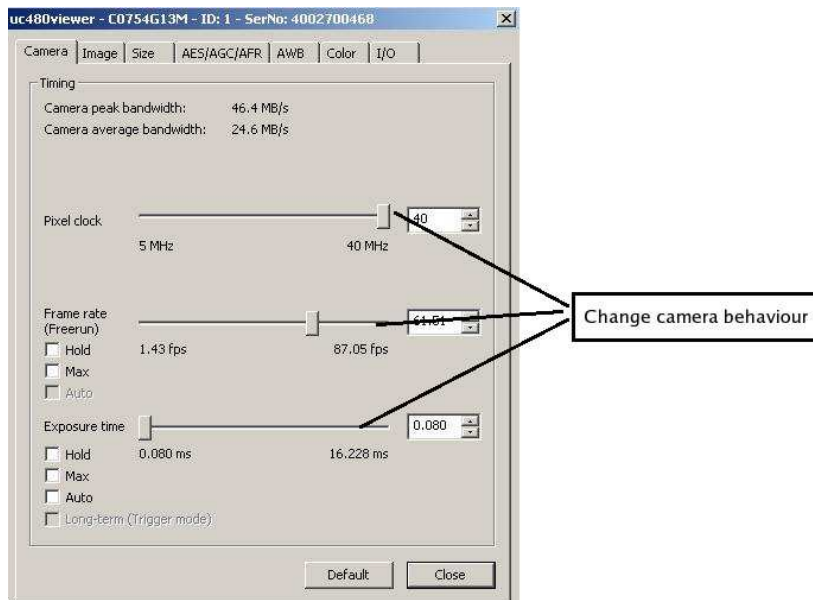


Figure 2: Camera properties.

3 Camera properties

In this exercise you will use the monochromatic Edmund Optics USB camera in a set-up with the laser and a $100\mu\text{m}$ slit.

*In this set-up we have to use the laser without dampening filter. If the camera gets directly exposed by the laser, the sensor will be damaged. **Only in combination with the slit the light level is not harmful for the sensor.** Therefore, do not remove the slit before you have switched off the laser and closed the camera cover.*

You will store images that will be used for more detailed analysis using IDL in the next exercise. Use a USB memory stick to save the images you need. You can use the Windows machine in the terminal room 116 on the ground floor to upload your data to your home directory. The images from the Edmund Optics USB cameras are saved as bitmaps, extension `.bmp`, and can be imported into IDL.

Exercise 3

Use the diffraction pattern in the live view of the camera to measure the width in μm of the pixels of the sensor and calculate the uncertainty in your measurement. Use the formula for single-slit diffraction $a \sin(\theta) = m\lambda$, where a is the slit width, and m the order of the minimum.

To record a proper image, one needs to make sure that the image is well exposed – the signal level should be as high as possible in order to minimize noise but one should avoid over-exposure. One should avoid to get too close to the maximum exposure level in order to avoid non-linear behavior of the sensor.

Exercise 4

Record a well exposed image of the diffraction pattern. Note the exposure time, frame rate and pixel clock of this image.

Standard operations to process “raw” images are corrections for *bias*, *dark current*, and *flat field*. The bias level is measured in total darkness and with the shortest exposure time possible. One would expect this level to correspond to a pixel value of 0 but in practice this level is set to a small value to account for digitization noise. In theory, the bias level should be identical for each pixel since no photoelectrons nor thermal electrons are generated. In reality, the bias level varies from pixel to pixel caused by various sources of noise.

A dark current is generated during integration due to generation of thermal electrons. The dark current is measured by blocking the light and exposing with the same integration time as the data that is to be corrected.

Flatfield correction compensates for sensitivity variations over the field of view. These sensitivity variations are due to pixel-to-pixel variations of the quantum efficiency – a uniform flood of photons on the sensor generates a dif-

ferent number of electrons for the different pixels. In addition, large scale variations in the sensitivity are caused by imperfections in the optical system such as uneven illumination and dust at various optical surfaces. A flat-field frame records the response of the entire optical system to a uniform (or “flat”) field of light. Whereas correcting for bias and dark current is trivial and straightforward, obtaining a good flat field can be a difficult and involved process. It is often not trivial to have a feature-less field of light going through the same optical path as for the science observations.

You will now record a number of bias, dark and flat exposures that will be used for further analysis in IDL.

Exercise 5

After switching off the laser and putting the dust cover on the camera, remove the slit from the beam. Then record calibration data as follows:

- Record 2 bias frames by turning down the exposure time to the minimum value.
- Record 5 dark frames with the same exposure time as in (3).
- Record a dark frame at the maximum exposure time.
- Remove the dust cover of the camera. Now we record a very basic type flat field image: use a white paper to reflect light from the ceiling into the camera. Make sure the flat image is well exposed by adjusting the integration time so that the average pixel value is between halfway to one-third to the maximum output of the camera. Record 16 flatfield images and note the exposure time.
- Close the dust cover and record 5 dark frames at the same exposure time as the flats.

3.1 Image analysis in IDL

Exercise 6

Load one bias frame and the dark frame with maximum exposure time into IDL – use the IDL routine `read_bmp`. Compare the two images: compute average, minimum and maximum pixel values, plot histograms of the pixel values and view the images on the screen. Is there much difference between these frames? Locate the pixel with maximum counts in pixel coordinates (x, y) for both the bias and the dark frame. Are they the same?

Exercise 7

Load both bias frames, B_1 and B_2 . Add them together and measure the mean

value of the central square region, 300 pixels on a side. The mean value is the quantity $\bar{B}_1 + \bar{B}_2$. Next, subtract one bias frame from the other, and measure the standard deviation for the central region.

Exercise 8

Subtracting the two bias frames removes any fixed bias patterns, leaving just the noise from the two bias frames $\sigma_{B_1-B_2}$, which is $\sqrt{2}$ times the noise of one bias frame.

Exercise 9

Do the same for two flat frames: compute for the central region $\bar{F}_1 + \bar{F}_2$ and the noise in two flat frames $\sigma_{F_1-F_2}$.

We have measured the mean of a signal level and the noise as its standard deviation in pixel counts, or analog-to-digital Units (ADU). There is a conversion factor g that relates 1 ADU to the number of actually measured electrons. Because one expects the signal to display Poisson statistics measured in electrons, one expects $\sigma_{\text{electrons}} = \sqrt{F_{\text{electrons}}}$. Since both σ and F have been multiplied by the conversion factor, we have actually measured $g\sigma_{\text{electrons}} = \sqrt{gF_{\text{electrons}}}$. Solving for g :

$$g = \frac{F_{\text{electrons}}}{\sigma_{\text{electrons}}^2} \text{ [electrons/ADU]}. \quad (1)$$

Correcting for the bias and noise related to the bias:

$$g = \frac{(\bar{F}_1 + \bar{F}_2) - (\bar{B}_1 + \bar{B}_2)}{(\sigma_{F_1-F_2}^2) - (\sigma_{B_1-B_2}^2)} \text{ [electrons/ADU]}. \quad (2)$$

Exercise 10

Compute the conversion factor g .

Exercise 11

The only source of noise in a bias frame should be the readout noise. Compute the readout noise in electrons.

Exercise 12

You have recorded 16 flat frames. Use these flat frames to see how the **normalised** noise decreases by adding frames. Compute successively $\sigma_{F_1-F_2}$, $\sigma_{(F_1+F_3)-(F_2+F_4)}$, $\sigma_{(F_1+F_3+F_5)-(F_2+F_4+F_6)}$, ... until you have used all flat frames. Plot these values **normalised** by the number of frames used (divide by the number of pairs) and see that the noise decreases how you expect.

Exercise 13

Load the image with the diffraction pattern from exercise (3). View the image and identify patterns that could be attributed to imperfections in the optical

path and that should be removed by flatfield correction. Construct a "master" flat by (1) averaging all flat exposures F_{average} , (2) averaging all corresponding darks D_{average} , and (3) normalizing $F_{\text{average}} - D_{\text{average}}$ to its average. Correct the diffraction image by first correcting for dark current and then dividing by the master normalized flat. Do you see any improvement? What is the basic flaw in constructing a flat field the way we did?

4 Report

The report should contain an explanation of how you did each exercise, with necessary figures and images etc. included in the report. Exercises 1-5 will be performed in the lab, while the rest can be done later.