The Detailed Characterization of a CCD Detector

Topics:

- Introduction
- The temperature-dependence of the dark-current
- Measuring the read-out-noise
- Measuring the gain
- Worksheet
- Other activities

back

Introduction

While standard bias, dark-current, and flat-field calibrations are enough to remove the cosmetic errors of raw CCD images, in order to measure things in CCD images quantitatively, one has to know more about the properties of the detector.

One of the most important properties of a CCD is the so-called READ-OUT NOISE : the noise which occurs whenever the image is read out by the camera electronics, independent of how long the image was exposed. This noise determines how faint a signal one can detect: once the signal is at the level of the read-out-noise, it becomes very difficult to see faint objects no matter how long one exposes the images.

Every image contains a certain amount of noise due simply to the fact that the original signal is composed of individual detected photons -- so-called POISSON-NOISE. In order to understand the exact *amount* of this noise, another important property must be measured: the GAIN, usually defined as the number of original photoelectrons per number finally stored in the digital image.

Finally, one should know what signal is constantly produced by the temperature of the detector - the DARK-CURRENT. This noise increases as the exposure time is increased and is also a form of

Possion-noise. This effect can be measured while the CCD is being cooled down (if the camera has active cooling) or by making exposures with a very warm and very cold camera (e.g. making measurements during a cold winter night and in a warm room).

Temperature-dependence of the dark-current

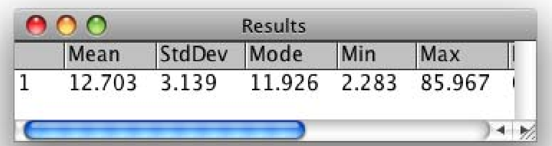
Measuring the read-out-noise

The READ-OUT-NOISE (RON) is easily calculated from the set of bias observations described before in ▸Creating a bias calibration image◂:

1. Load the raw bias images into a stack using the command: `File > Import > Image Sequence ...` (you may need to specify the names more precisely and not just the directory).

2. Compute the standard-deviation of the bias images pixel-by-pixel using the `Image > Stacks > Z Project ...` command, selecting the `Standard Deviation` option. The result is an image containing the RON for each pixel of the CCD.

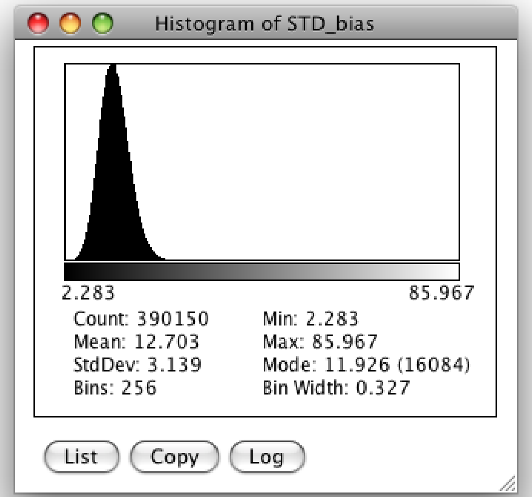
3. To calculate the typical RON of the camera, type CNTRL-M (OSX: Apple-M) to measure the average value of all pixels (see the info about ImageJ's ▸ measure ◂ command in the chapter about ImageJ). If the average doesn't appear in the Results table, you have to set which things are measured in the `Analyze > Set Measurements ...` menu.



Results

	Mean	StdDev	Mode	Min	Max
1	12.703	3.139	11.926	2.283	85.967

4. To see what range of RON are present, create a histogram of the RON measurements: `Analyze > Histogram` will produce a small histogram image labeled with all of the statistical properties of the RON.



The value you get from the bias images is in the arbitrary "counts" units which come directly from the camera. In order to express the RON in the natural units of *electrons per readout per pixel*, you have to measure the "gain".

Measuring the gain

Although the original signal measured by the camera was number N of photoelectrons, the image finally stored is a digitize version in units called COUNTS or sometimes ANALOG-TO-DIGITAL UNITS (ADU's), each COUNT corresponding to some number of photoelectrons. The conversion factor between the two units, the GAIN "g" (generally expressed as so many electrons per count), is set by the camera's manufacturer and must be measured. The simplest way to measure the gain is to use the noise properties of the signals.

The simplest analogy that can be used to understand the noise properties of digital images due to the fact that individual photons are detected is that each pixel is like a bucket stuck out in the rain for a certain time.

- If the number of raindrops hitting a particular area per time is small (it's only sprinkling), then during a given "exposure time" you may only collect a few or even no rain drops. Every time you repeat the "measurement", a different number of raindrops is collected,

but the number differs only by a small amount - sometimes you collect none, sometimes one, othertimes a few. The average difference in the number of raindrops collected is a measure of the "noise" in your measurement and is typically a few raindrops.

- If the amount of rain increases, it becomes more difficult to count individual raindrops, but it is clear that each "measurement" results is a different amount of water that differs by many more than just a few raindrops. In a hard rainstorm, the amount of water is so great that the individual raindrops are hardly noticeable and the different amounts of water collected are nearly indistinguishable.

It turns out that the uncertainty or STANDARD DEVIATION σ_N in the number N of discrete events (e.g. raindrops or photons), increases as the square-root of the number:

$$\sigma_N = N^{1/2}$$

Thus, the more events one measures, the larger the uncertainty in the final total number of measurements. Fortunately, the *relative* uncertainty - the ratio of the uncertainty to the total number - decreases as more events are recorded:

$$\sigma_N/N = N^{-1/2}$$

so that it always pays to measure more events. Since the uncertainty in the measurement shows up as a "noise" in the measurements, the inverse of this ratio is called the SIGNAL-TO-NOISE RATIO and it increases as the square-root of N.

Unfortunately, when a CCD pixel measures N photoelectrons, this signal is digitized and stored in COUNTS, not events. Fortunately, we can use the noise properties of the signal to measure the conversion factor between electrons and counts:

- after a given exposure i, assume a pixel measured N_i photoelectrons;
- this signal was output as $C_i = N_i/g$ counts, where N_i is initially

unknown;

- when repeated many times under the same conditions, the standard deviation measured is σ_C counts, corresponding to an unknown σ_N photoelectrons;
- using the definition of C_i, we can predict how much noise σ_C we should see depending upon the mean signal <C> or <N>:

$$\&sigma_N = \langle N \rangle^{1/2} = (\langle C \rangle\ g)^{1/2} = \&sigma_C\ g$$

i.e.

$$\&sigma_C^2 = \langle C \rangle / g.$$

Thus, one merely has to measure the mean signal <C> and the square of the noise (the so-called "variance") of a series of nearly identical exposures and the two are connected by the proportionality constant 1/g. The trickiest part of this measurement is getting a set of nearly identical exposures.

Worksheet

Task	Description	Result
1.	Measure the temperature dependence of the dark-current by measuring the dark-current from a series of bias-subtracted dark images with the same exposure time but different temperatures.	A plot of dark-current as a function of temperature for the entire chip on average and for individual pixels with large dark-currents.
2.	Calculate the standard deviation per pixel of the bias images (import sequence into a stack, Z-project using the `Standard Deviation` option).	Image of read-out-noise per pixel in counts.
3.	Calculate the mean value of the read-out-noise image using the *ImageJ* measure command.	Mean read-out-noise of CCD in counts.
4.	Calculate the mean level and standard deviation per pixel for a sequence of identical well-exposed images.	Mean level and standard deviation per pixel images.
5.	Calculate the gain of each pixel and the mean gain of the CCD.	g [e-/count]

Other Activities:

- *Creating a bias calibration image*
- *Creating a dark-current calibration image*
- *Creating a flatfield calibration image*
- *Creating a flatfield calibration image from sky-flats*

Version: 2007-02-18