ASTRONOMY
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STUDY OF CHARACTERISTICS OF CHARGE-COUPLED DEVICES (CCD)

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Contents

Keywords: CCD, Photometric observation, Astrometry

Level and stream: UG/PG (Science, Engineering)

Prerequisites: Basics of semiconductors, CCD devices

Learning objective:

1. To estimate the average response of the given CCD pixels in terms of the number of photo-electrons per ADC counts by assuming the photo-electron statistics (Poissonian) is the only source of fluctuations.
2. To estimate the flat filed response of the CCD

Materials: CCD, camera PC/Laptop, cables, CCD controller

1 | Introduction

The study of the characteristics of charge-coupled devices (CCDs) involves understanding the operational principles of charge-coupled devices and analysing their performance parameters. The CCDs are electronic devices that capture and convert optical light into digital readable data. The CCD consist of an array of light-sensitive elements called pixels. Each pixel is capable of converting incident light photons into electrical charges. The photons incident on the CCD are absorbed by, usually made of silicon, a semiconductor material. The absorbed photons generate electron-hole pairs, and the electrons are collected in potential wells created by applying a voltage to the device. These potential wells are arranged in a row or column pattern, allowing the charges to be shifted and transferred through the device in a controlled manner. The accumulated charges are read out and digitised to form an image.

Each pixel in a CCD possesses specific characteristics that affect the overall device performance. The CCD characterisation mainly depends on these characteristics, namely Quantum efficiency, Fill factor, Noise, Readout noise and Dynamic Range.
Quantum efficiency (QE)measures the pixel's ability to convert photons into electrons. Higher QE means more efficient light capture and the best quality CCD for greater the QE. Based on the QE, one can select and decide the quality of the CCD for astronomical observation. The fill factor describes the fraction of the pixel area sensitive to light. A higher fill factor allows more light to be captured. The CCDs can be subject to various types of noise, such as dark current noise (resulting from thermal effects), readout noise (introduced during signal readout), and quantisation noise (arising from analogue-to-digital conversion). Understanding and minimising noise is crucial for optimal image quality. The dynamic range refers to the ability of a pixel to detect and accurately represent a wide range of light intensities. A higher dynamic range allows for better differentiation between bright and dark regions in an image.

Calibration is one of the important factors in CCD imaging and along with corrections.
To ensure accurate and high-quality imaging, CCDs often require calibration and correction techniques in the process to get the final image or get the science image. Important steps must be followed to get the final calibrated image, like taking dark, flat, and biased frames.
Dark frames are images taken with the CCD sensor covered with a cap or any other means so any light should not fall on the CCD sensor, it is used to measure and subtract the dark current noise from the light frame. Flat fielding corrects for pixel-to-pixel variations in sensitivity by dividing the image by a flat field frame. Bad pixels exhibit abnormal behaviour and can be identified and replaced with interpolated values based on neighbouring pixels. Non-Uniformity Correction (NUC) compensates for spatial variations in pixel response, resulting in a more uniform image.

By studying these characteristics and employing appropriate calibration and correction techniques, researchers and engineers can optimise CCD performance for various applications, such as digital photography, scientific imaging, and astronomy.

2 | Procedure

2.1 | Connect the CCD camera to the PC/Laptop

1. Please read carefully the ST-4 CCD manual given to you. It is given the manual on how to connect the CCD.
2. On the controller box, the port is written RS232c. It is to be connected to the PC cable.
3. Caution, always first connect the power supply cable and then only switch on the power supply.
4. Caution never-never disconnect the cable to the CCD head.

2.2 | Connect the CCD camera to the PC/Laptop

1. CCD controlling program is in the STUDENTS sub-directory on the C drive of the PC/AT
2. At the DOS prompt, type cdstudents and press Enter.
3. Now type CCD and press Enter.
4. The CCD menu will come on the screen.
5. Please refer to the manual to explain the various menu items or ask your instructor.
6. Use the GRAB menu to acquire the data from the CCD and the DISPLAY menu to analyse the data.
7. CAUTION always exit for the CCD menu from the QUIT mode only. Never abort the program prematurely. e. by pressing Ctrl-Alt-Del or Ctrl-C or Ctrl-y etc.

2.3 | Exercise - 1

1. Keeping the CCD head closed with the cap. GRAB a frame for, say, 2 minutes of exposure.
2. Check the value of the background. It should be around 210.
3. If it is less, increase the integration time (or decrease it if more) to get the background around 200. This is your time T1.
4. Now, take the cursor to the given x and y (say x=48 and y=163) position and note the pixel's value.
5. Now shift the cursor one position up (y-1 or 182) and record this pixel's value again. Similarly, record the values for (y+1). (x-1) and (x+1).
6. Repeat steps 4 and 5 for 10 times for the T1 and find the mean intensity and mean fluctuation for the pixels. 7. Estimate the response factor by assuming the property of the Poisson statistics.

2.4 | Sample table to record the data

X, Y (48, 163)	X+1, Y (49,163)	X-1, Y (47, 163)	X, Y+1 (48, 164)	X, Y-1 (48,163)
201	194	194	213	195
211	215	204	211	209
211	214	212	196	197
225	201	220	226	216
193	211	199	212	207

Mean = $\boldsymbol{\mu} = 1/N \ \sum Xi$

Standard deviation = $\sigma = \sqrt{(\text{average derivation})^2}$

$$\sigma = \{ \prec (xi - \boldsymbol{\mu}) \succ \} 1/2$$

For posissonian statistics $\sigma^2 = \boldsymbol{\mu}$

Conversion factor = CF = $\dfrac{\text{mean}}{(\text{std dev})^2} \times \dfrac{\text{counts}}{\text{photo electron}}$

2.5 | Sample results based on the above reading

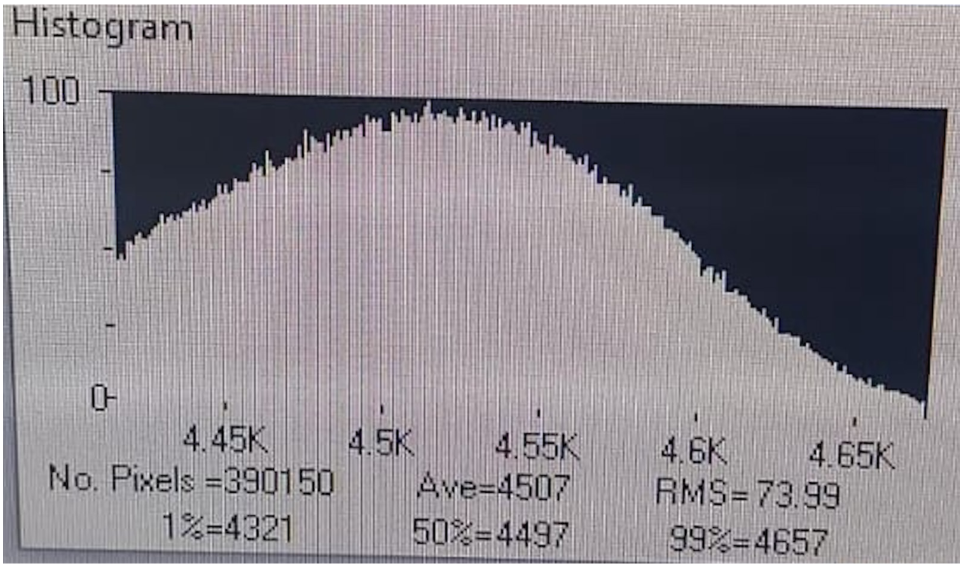
X, Y (48, 163)	X+1, Y (49,163)	X-1, Y (47, 163)	X, Y+1 (48, 164)	X, Y-1 (48,163)
201	194	194	213	195
211	215	204	211	209
211	214	212	196	197
225	201	220	226	216
193	211	199	212	207

Mean				
208	207	206	212	205
Standard deviation				
11	8	9	10	8
Conversioon factor				
2	3	2	2	3
No of photons per ADU				
3	5	4	4	6
Average				
4				

2.6 | Exercise - 2

1. Remove the black cap of the CCD over. You will find layers of tracing sheets used for diffusing the light.
2. Point the CCD to some uniform source of light. In practice, it is very difficult to get a very uniform source, so the entrance of the CCD is covered with sheets of tracing sheet, and the CCD is pointed to a uniformly illuminated wall. (Note:- Clear sky at dusk or down is a very good source of uniform source of light… using the adjacent wall)
3. Now take a very small exposure of, say, 1 second.
4. Check the count value. The exposure time for which the count value is, again, around 200 is T2.
5. Store this data on the hard disk using the SAVE option of the i/o menu.
6. Now close the esp, and for the T2, take one more exposure. This is your dark frame.
7. With the help of the dark subtract menu subtract the frame from the earlier frame.
8. Make a histogram plot (histogram mode) of this image with the x-axis as grey levels (0-255) and the y-axis as numbers of the pixel (0-31680).
9. Any deviations from the sharp histogram show variations from the perfect flatness is response of the CCD.
10. Estimate the percentage variation in the sensitivity of the pixels and indicate by this histogram.
11. Make sure this experiment is done in the late evening to avoid the CCD saturation.

3 | Results



Ideally, this should be a delta function for a perfect CCD, Ths histogram spread is seen because
1) non-uniformity of the illumination
2) pixel to pixel variation due to cosmetic effects

4 | References

1. Book: "Scientific Charge-Coupled Devices" by James R. Janesick
2. "Charge-Coupled Devices and Their Applications" by Eric R. Fossum
3. "Characterization of Charge-Coupled Devices" by Albert J. P. Theuwissen
4. "CCD Imaging - Understanding and Optimizing CCD Performance" by Hamamatsu Photonics
5. "CCD Astronomy: Construction and Use of an Astronomical CCD Camera" by Christian Buil