

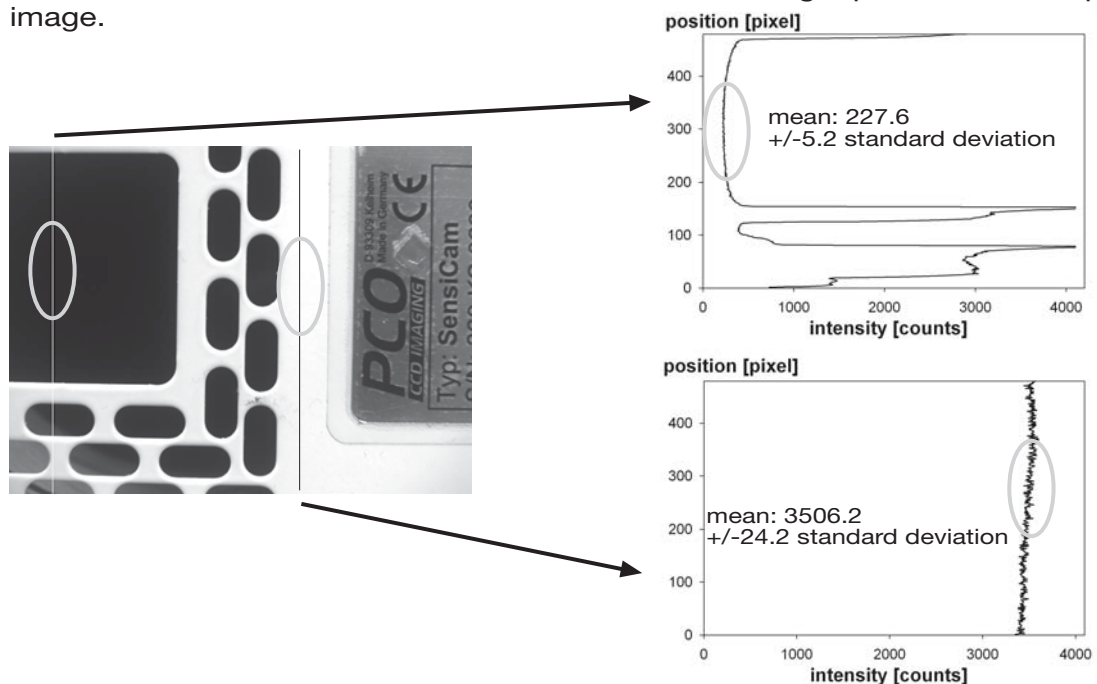
noise – general

Noise is an unwanted signal, either contained in the relevant light signal or added to it by the imaging process. Noise prevents accurate measurement and evaluation of the light signal distribution (image). Noise usually comes from three main sources:

1. Photon or shot noise
2. CCD image sensor noise
3. Read out or amplifier noise

photon or shot noise

As a natural part of light, the number of photons impinging on a CCD image sensor that generates charge carriers is not exact, and can only be described using probability. Photon or shot noise is a characteristic of light, which is best described by a statistical distribution with an uncertainty. This noise is directly proportional to the magnitude of the light signal itself, seen below with the different standard deviations marked in the dark and bright parts of the sample image.



The camera casing detail and the graphs illustrate pixel columns that have been extracted at the position of the 2 lines in the photo. In the range of the 2 ellipses, the mean and standard deviation has been calculated using more than 21 values for comparison. Results are shown in the graphs.

CCD image sensor noise

Noise influences that may occur on a CCD image sensor include:

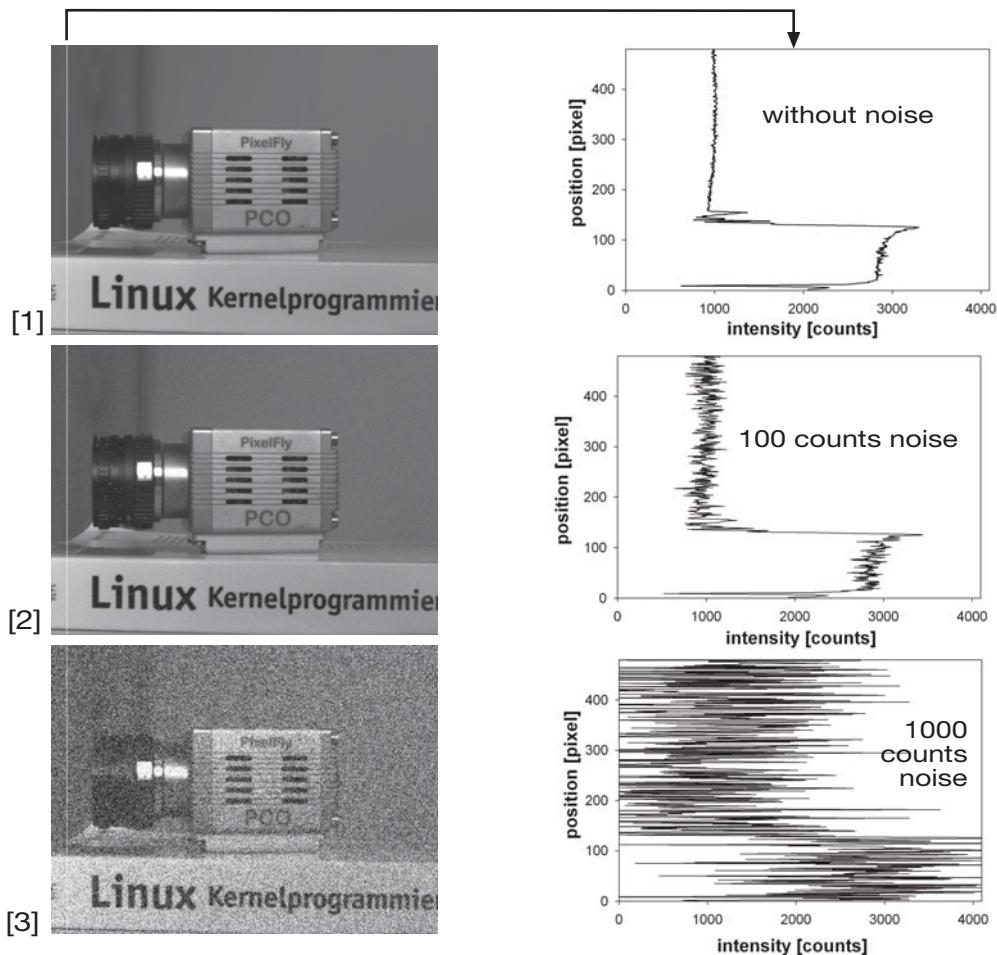
- "dark charge" or "dark current" (e.g. thermally induced charge carriers)
- transfer noise (additional or lost charge carriers due to shift of charge carriers between the registers of a CCD image sensor)
- fixed pattern noise (spatially fixed differences in noise behavior or sensitivity)
- noise that is dependent on the setpoint of the CCD image sensor, etc..

Some of the phenomena are explained in greater detail in the "Calculating Noise" section.

noise – general

read out noise

A noise signal can be added during the conversion of the charge carriers into a voltage signal and the subsequent processing and analog-to-digital conversion. This is caused by the amplifier processing chain and the actual analog-to-digital conversion process. This noise is uniformly added to the image. The images below illustrate the influence of various levels of noise signal (100 and 1000 counts) on the image quality of a 12 bit with a scaling range of 0-4095 counts.



The series of images (from top left to bottom):

- [1] Original image (0-4095 counts, 12 bit) with lines indicating the position of the extracted pixel column (shown in the graphs to the right of the images)
 - [2] Same image with noise amplitude of 100 counts
 - [3] Same image with noise amplitude of 1000 counts
- (all images scaled with 0-255 gray levels for a range of 0-4095 counts)

noise – general

calculating noise

photon or shot noise

n_{photon} ...noise electrons due to photon noise

$$n_{\text{photon}} = \sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta}$$

with Φ - light power [W/m^2], $h\nu$ - photon energy [Ws], t - exposure time [s],
 A - pixel area [m^2] and η - quantum efficiency

CCD noise

n_{CCD} ...noise electrons due to CCD-noise

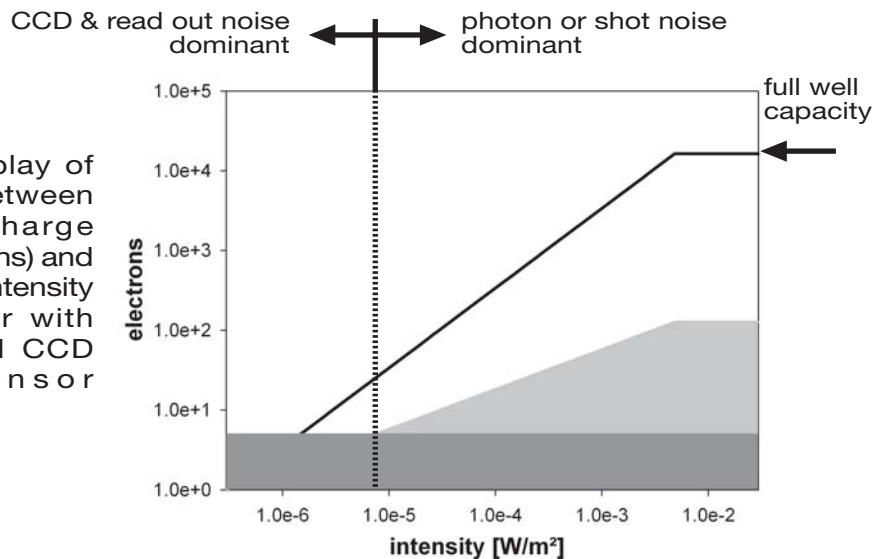
read out noise

n_{readout} ...noise electrons due to read out noise

Since all of the three noise sources are not correlated, the total number of noise electrons is given by:

$$n_{\text{total}} = \sqrt{\left(\sqrt{\frac{\Phi}{h \cdot \nu} \cdot t \cdot A \cdot \eta} \right)^2 + n_{\text{CCD}}^2 + n_{\text{readout}}^2}$$

Graphical display of the relation between generated charge carriers (electrons) and the impinging intensity or light power with regard to real CCD image sensor specifications.



assumed specifications:
 $\lambda = 540\text{nm}$, $A = 41.6\mu\text{m}^2$, $t = 50\text{ms}$, $\eta = (0.6 \text{ at } 540\text{nm})$,
 CCD read out noise = 5 e^- , full well capacity = 16384 e^- .