Adaptive Dark Pulses Cancellation Process

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The principle:

The object of this technique is to achieve the cancellation of the pulses of signal that happen at some pixels of a DSLR image. Such pixel photo-diodes have an inverse current (leakage like) larger than in normal pixels (during the exposure the photo-diode is under inverse polarization, expected non conductive). That currents are proportional to an exponential function of the temperature of the diode, then the resulting electron charge of the pixel is proportional to the image exposure time (Q=I x t).

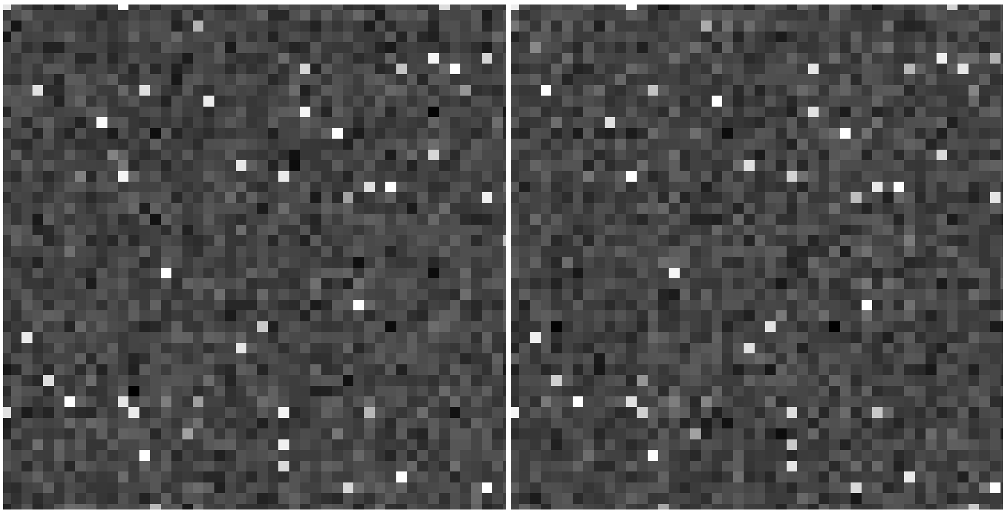

Fig 1 Same pixels of two images. The bright pixels are the "pulses" of dark currents, target of the dark process. They are same from one image to the next that allows to cancel them by subtraction of dark images. The background noise is well random.

The classical way to cancel such dark signal pulses is to make dark images (sensor in the full dark) under condition identical to the sky images and subtract the dark image from the sky image. In DSLR that technique is not perfect as the temperature is not under control and this process is observation time consuming. The "adaptive dark technique" (ADT) is designed to overcome such drawbacks. It's based on the assumption the amplitudes (electron charge) of the pulses in the image are globally proportional to the exposure time and proportional to the effect of the temperature (as an example a delta of +6°C increases all currents, small or large, of the pattern by a factor 2). The experience shows that the temperature distribution in a present CMOS sensor architecture is well uniform (very low dissipation of CMOS and active electronic elements well distributed across the chip). By the way the ADT provides very good results, better canceling the dark pulses than other techniques. If the temperature was non uniform across the sensor it would be very possible to apply a mapping of the correction but the case has not been seen at day.

Description of the ADT:

Master-Dark Images Preparation

The dark images can be exposed at any time before the sky image processing, the experience shows that a good master-dark can be used for several months up to the point the CMOS sensor get some sensible aging.

The dark images of DSLR are taken at ambient temperature, possibly a bit high (25°C). With recent DSLR, the dark current being low, the total exposure shall be as long as one hour (ie 6 x 10 minutes). The goal is to get enough dark signal at high SNR. However individual exposure shall not saturate. The ISO setting should be low, a good choice is the 1 e^-/ ADU level, usually about ISO 200. Photometry is always done at low ISO, 100 to 400 ISO is the typical range, at higher ISO the dynamic is impacted. As usual those images are stacked (no median) using 32 bits signed integer or floating point type calculation. The systematic bias (constant) that exists in various cameras shall be subtracted (ie 2048 ADU in recent EOS). The classical offset process is not recommended in case of recent CMOS sensor, their static pattern is extremely weak and (by the way) polluted by spurious random signals that makes it worst than doing nothing.

Master-Dark Processing

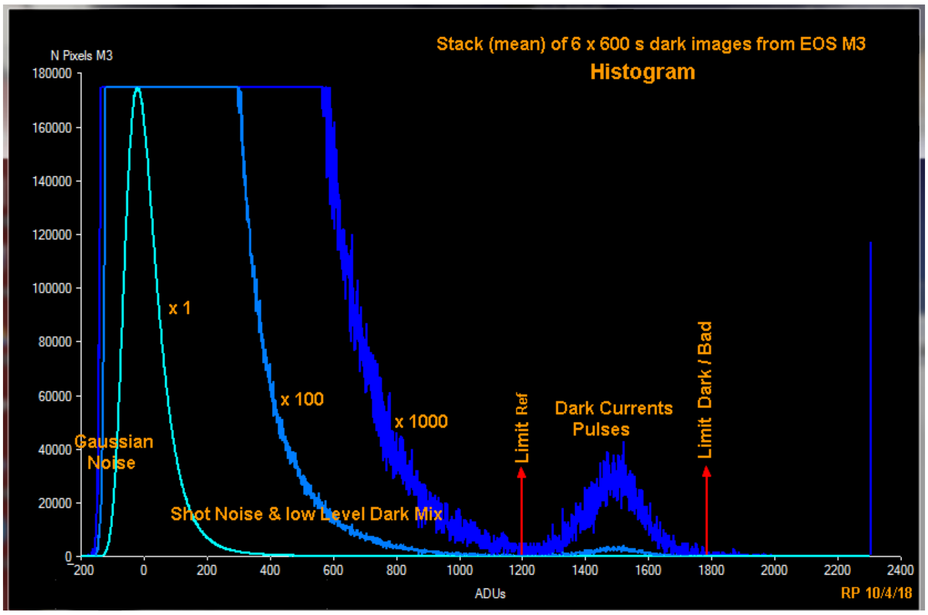

Fig 2 Histogram of dark of an EOS M3 (24 Mpix), the number of dark pulse pixels is small compared to all others having random noise, we need to push the scale by x1000 to well see them. Here the M3 has very few dark pulses, one hour of cumulative exposure was needed to get a good reference. At same time such long dark exposure makes obvious the shot noise due to the "normal" dark current of all other pixels.

It starts making an histogram of the signal of all pixels of the dark stack. If the exposure is right the histogram shows three zones of different distribution. Around the zero ADU level we have a Gaussian distribution peak, this is the random noise of Nyquist-Johnson nature plus shot noise from the normal uniform dark current. Then a second distribution should be visible at higher levels (ie. 500 ~ 2000 ADU). This is the distribution of our dark current pulses. The amplitude (number of pixels involved) is much lower than such of the random noise area, it could be necessary to push the graph scale to see them. After, most of the higher levels are free of pixels count, and at end we have a small number of pixels. Those pixels are not properly working, not usable for photometry, they should be processed as cosmetic or flagged as invalid for photometry.

From that histogram we shall define two limits, one between the random noise area and the dark pulses, and the second between the dark pulses and the bad pixels.

After that the software selects the pixels that are in between the two limits and make a table of their addresses into the image. For a better efficiency a second table of their ADU amplitude is also built, last the median value is computed.

The Master-Dark file is built including the two reference tables of dark impulses (addresses, amplitudes), their median value, the systematic bias level, the dark image. Some other info could be added (date, camera, limits, condition...).

In present CMOS the number of involved pixels is a small percent of the total, few thousands for a 24 mega-pixel sensor, plus maybe 100 bad pixels. The resulting computing takes little time.

Adaptive Dark Subtraction, Sky Image Processing

The first operation is to measure the amplitude of the dark impulses charge in the pixels of the sky image at the addresses recorded in the reference tables of the master-dark file.

The ADU level of each selected pixel is then compared to the mean level of their surrounding. The difference is recorded. At end we have typically several thousands ADU values that make a good statistic basis of the dark currents of the sky image. To eliminate possible out-layers (saturation, peak of noise, presence of star...) we determine the global level using a median (or sigma clipping...).
The ratio of the sky image median to the recorded dark median is the rescaling factor we would then use.

At that point we have several possible choices:

- The sky image median is very low, like a couple of electrons (1 e-/ADU about ISO 200): this is usually well below the noise level of the image, best is probably to not subtract any dark from the sky image. This reduces the processing time and avoid to add a few random noise. With recent DSLR CMOS this case is not uncommon in winter or even intermediate seasons.

- The sky median is a couple of times the noise level of the image: that means the lower level dark charges, other than the ones of the reference table, are much below the noise. There we have the choice to only correct the pixels of the reference table. This is just to apply the ratio of the medians to the recorded pulse ADU levels of the reference table and subtract it from the recorded addresses of the sky image. This avoids to add some more random noise to most of the sky image.

- The sky median is high, several 10% of the master-dark reference, here we subtract all the master-dark rescaled by the ratio of the medians.

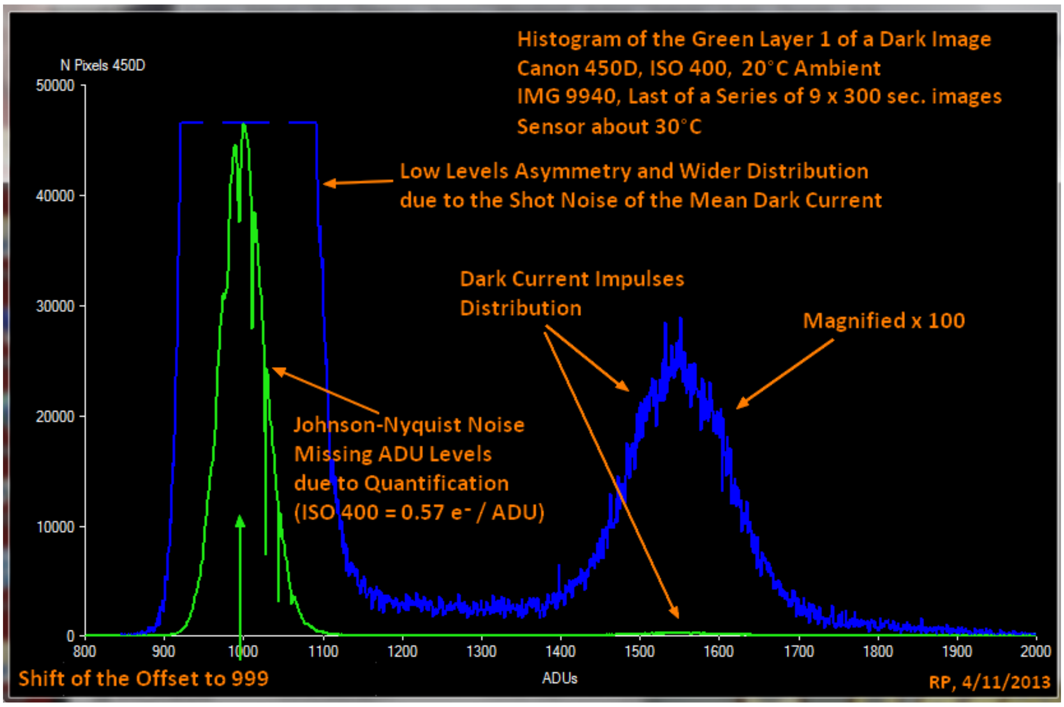

Fig 3 Another histogram from an old EOS 450D, interesting to compare to the EOS M3 (Fig 2) After only 300 seconds of exposure the dark pulses are much more than the M3 in one hour. In such shorter time the shot noise is just a little visible. Here the systematic offset of 1024 has not been subtracted.

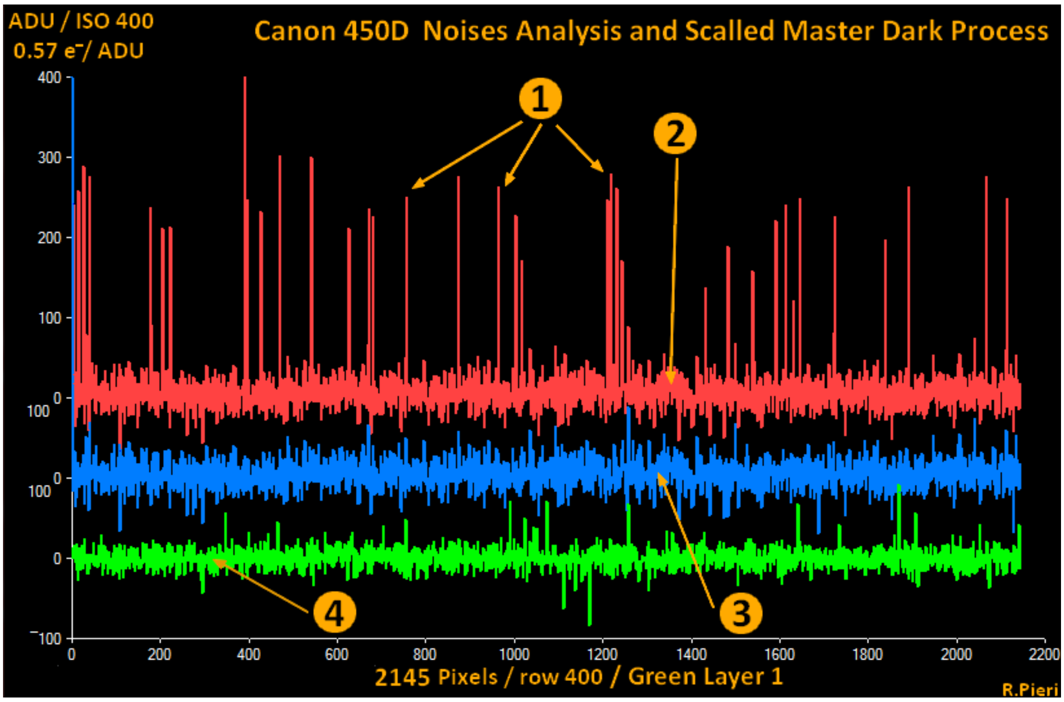

Fig 4 This is the signal from one row of pixel of the EOS 450D. (1) points the dark current charge we call "pulse" as it looks like an electronic pulse. (2) is random noise, combination of Nyquist-Johnson "Gaussian" noise and shot noise from the elevated black level. (3) is the random residual after the adaptive dark process. It is to be compared to (4) from a short exposure showing only Gaussian noise.