WHY CAMERA CALIBRATION USING VARIANCE DOESN'T WORK FOR PHOTORESPONSE CALIBRATION OF SCIENTIFIC CMOS (sCMOS) CAMERAS (AND OTHER PHOTODETECTORS)

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Unless corrected, photoresponse inaccuracies and noise in images can introduce artifacts in computational imaging, such as localization microscopy, especially when statisical estimation methods such as maximum likelihood estimation are used. The architecture of "scientific" CMOS (sCMOS) camera differs from CCD and EMCCD cameras, and it often believed that photoresponse non-uniformity (PRNU) is relatively high in CMOS cameras. We show through careful measurements of production cameras that photoresponse is highly uniform across the entire array at all light levels, while pixel variance is non-uniform and should be considered on an individual pixel basis. Furthermore, using pixel variance is fundamentally an inaccurate method to "calibrate" pixel response, and may degrade camera photoresponse uniformity from factory calibrations.

In CMOS cameras, the charge to voltage conversion is separate for each pixel and each column has independent amplifiers and analog to digital converters; additionally the quantum efficiency is pixel dependent. The "raw" output from the CMOS image sensor includes pixel-to-pixel variability in the read noise, quantum efficiency, gain, offset and dark current; therefore scientific camera manufacturers digitally calibrate and correct the raw signal from the CMOS image sensors.

To determine the individual pixel output accuracy for production Hamamatsu ORCA Flash 4.0 V3 sCMOS cameras, we measure the *distributions* and *spatial maps* of dark offset, and photoresponse uniformity (Fig. 1), and overall linearity. Individual pixel variance is modelled as the sum of two terms: dark variance (read noise) plus a term proportional to the signal (Fig. 2). Measurements are taken with highly uniform and controlled illumination over low light conditions from dark conditions and at multiple light levels between ~20 to ~30,000 photons / pixel per frame.

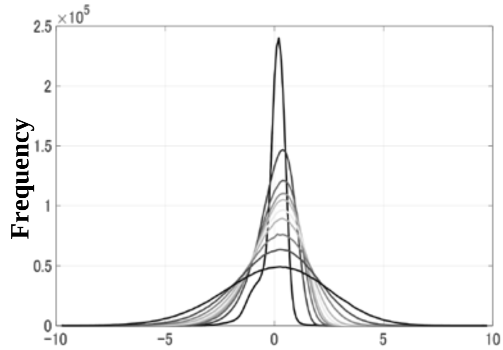

Fig. 1. Histograms of absolute error of low-light photoresponse. Absolute error shows the difference of pixel value from the average of all pixels at various light levels from dark to 1370 photoelectrons.

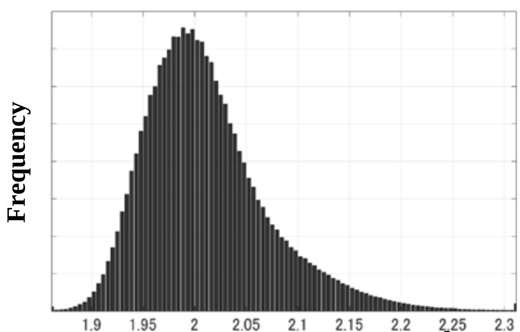

Fig. 2. Histogram of variance coefficients K_{xy} determined from a weighted least-square fit of total pixel variance $\sigma_t^2 = K_{xy}S + \sigma_d^2$. S is the mean signal (DN) in the pixel at various light levels, σ_t^2 is the temporal variance (DN^2) and σ_d^2 is the dark variance (DN^2).