Nonlinearity corrections of spectrographs using combinatorial methods

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Signal or gray-level linearities of spectrographs have been determined using a dual-path combinatorial method. Spectrographs were characterized for nonlinearities at fixed integration times using the NIST beamconjoiner apparatus. The 120 dependent signals were then analysed using nonlinear least squares fit with 40 independent signals and a 6th order polynomial as variables. The uncertainties of the nonlinearity corrections determined from the residuals of the fits were found to be 0.2 % (*k*=2) over the range of signals from 30 to 30,000. The resulting nonlinearity corrections were also compared with those measured using a constant optical source and varying integration times.

INTRODUCTION

The uses of spectrographs in radiometry and photometry are increasing due to the need for spectral information which can be used to better interpret measurement results. Since calibrations of these spectrographs can be performed only over a limited set of experimental conditions while the instruments can be used to measure widely varying optical levels, lack of knowledge about the linearities of these instruments can lead to large uncertainties in the final data products.

In the past, some laboratories have based their linearity characterizations of spectrographs on separately calibrated reference photodiodes which are used to simultaneously monitor the incident radiation on the spectrographs [1]. Others have used a dual-path method and measured mean-signal ratios which are then multiplied together to determine nonlinearity correction factors [2]. Both techniques have deficiencies, such as sparsity of points in the first method or the need to form a product of all the signal ratios to determine nonlinearity factors.

In this work, we describe the use of the NIST beamconjoiner setup [3] to determine nonlinearity correction factors of spectrographs.

EXPERIMENTAL SETUP

Briefly, the beamconjoiner is a dual-path setup using a single 100 W quartz-tungsten halogen (QTH) lamp with an MR16 reflector. The single beam is split into two paths as shown in Fig. 1 and then recombined onto the detector or the device-under-test. A total of 120 signals can be measured during a single run. Each of the 40 independent fluxes along with polynomial correction terms are solved using nonlinear least-square fit of the over-determined system of equations.

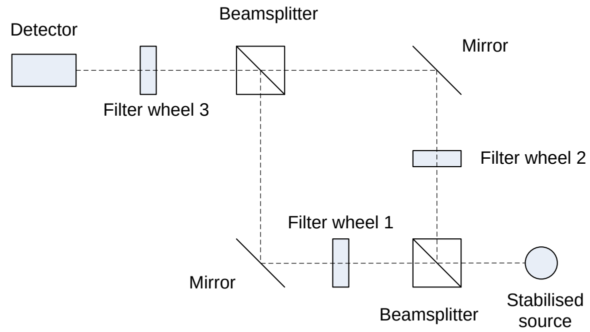

Figure 1 The NIST beamconjoiner apparatus for linearity testing of optical sensors. A 100 W QTH lamp was used as the source for these measurements.

Each signal can be written as a response to the incident flux or conversely, each flux results in signal as a function of the flux,

$$\Phi(i,j,k) = \Phi(i,j) + \phi(j,k) = r_o + s(i,j,k) + r_2 \cdot s^2(i,j,k) + \ldots + r_n \cdot s^n(i,j,k) \qquad (1)$$

where $\phi(i,j,k)$ denote the flux, $s(i,j,k)$ is the measured signal at the detector, and r_o, r_2, …, r_n are the coefficients which relate the signal to the flux.

A typical measurement run with 120 spectra is shown in Fig. 2. Before each run, the filter wheels are positioned to the maximum transmittance, and then integration time of the spectrograph is adjusted such that signals are not saturated. A spectrum is taken for each filter wheel combination and plotted as digital number (DN) over the integration time. For the analysis, only the averaged signals from the plateau region near the center of the spectra are analysed. This is to have constant nonlinearity corrections for pixel-averaged signals.

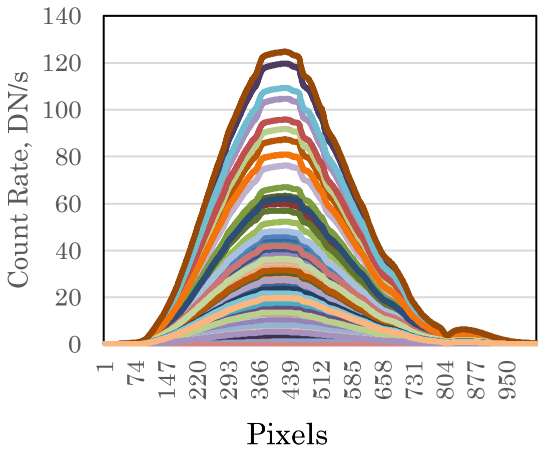

Figure 2. 120 spectra taken using a spectragraph during a single measurement run using the beamconjoiner. Integration time of 240 ms was used. The spectral range is from about 300 nm to 1100 nm. The averaged signals at the middle plateau were used for linearity fits.

ANALYSIS

The measured net signals ratioed to calculated fluxes are plotted in Fig. 3a as a function of the net signal along with the 6th order polynomial to correct the

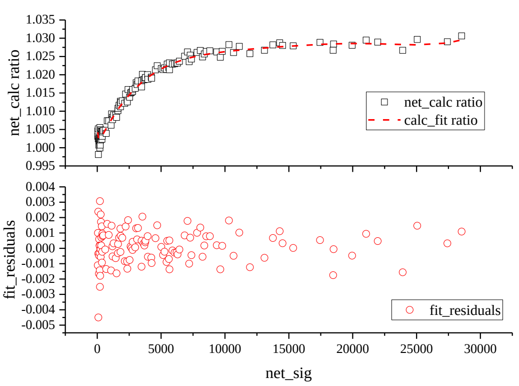

Figure 3. (a) The ratios of net measured signals to the fitted signals without the polynomial corrections. Nonlinearities of up to 3 % can be perceived. The polynomial correction function is also plotted. (b) The residuals of the fit showing 0.2 % (*k*=2) residuals.

nonlinearity. Without any corrections, the deviation of ratios from unity clearly indicates the presence of nonlinear behavior of up to 3 %. Introducing a 6th order polynomial correction reduces the deviations to about 0.2 % (k=2) as observed in Fig. 3b.

These nonlinearity corrections were further checked by measuring a constant radiation source with changing integration times to examine whether the count rates were linear. The 3 % nonlinearity could be clearly measured in the deviations of the count rate although with higher noise and at fewer signal levels as can be measured using the beamconjoiner setup.

DISCUSSION AND CONCLUSIONS

We demonstrate that the combinatorial method can be used to characterize the nonlinearity corrections of spectrographs. These focal-plane arrays exhibit substantially greater nonlinearities than single element detectors.

In this work, only the gray-level or the signal-dependent nonlinearity was characterized. Spectrographs could have integration-time-dependent nonlinearities, and methods to examine such dependences using the beamconjoiner method are being explored.

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