Everything you always wanted to know about flat-fielding but were afraid to ask

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Outline

- Purpose
- Part 1: Noise
- Part 2: Photon Transfer Analysis: basic concepts (tools we'll use)
- Part 3: Flat Fielding Basic Concepts: what it does, how it works, performance measurement
- Part 4: Making Master Flats: what level of signal, how many exposures
- Part 5: Field Techniques: taking sky flats, qualifying a master flat prior to deployment

Purpose

- The purpose of this material is to teach
  - What flat fielding does
  - How it works
  - How to quantify results
  - Introduction and use of basic camera analysis tools/techniques
  - How to design an optimized flat fielding protocol for your camera

Part 1: Noise

- Image noise sources
- Noise Equation
- Graphical Representation

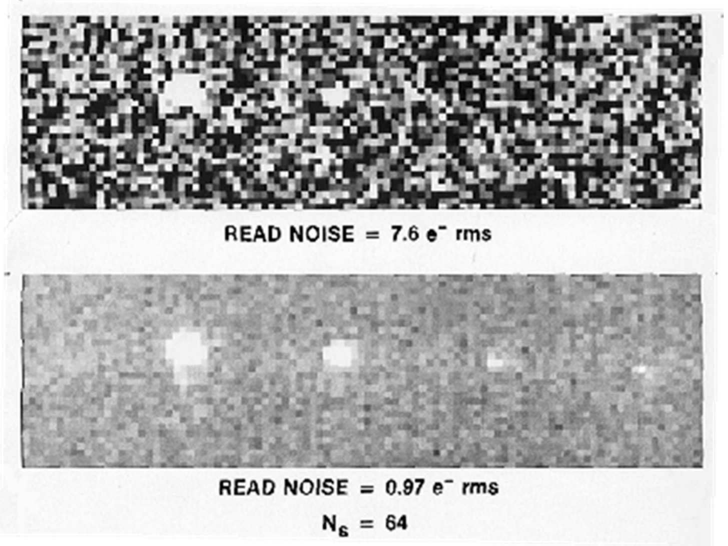
Image Noise Sources

- For an unmodulated image (flat field image), the key noise sources* are
  - Read noise
  - Signal Shot Noise
  - Fixed Pattern Noise
- Depending on signal level any of them can dominate the noise in a single image frame

*neglecting dark signal noise sources which can be managed by cooling

Read Noise

- The read noise is the noise observed in an image when no signal is present
- The noise in a bias frame approximates the read noise
  - zero length exposure
  - no light applied
  - bias frame noise differs from read noise floor by dark signal accumulation during finite readout time
- Read noise can obliterate faint signals

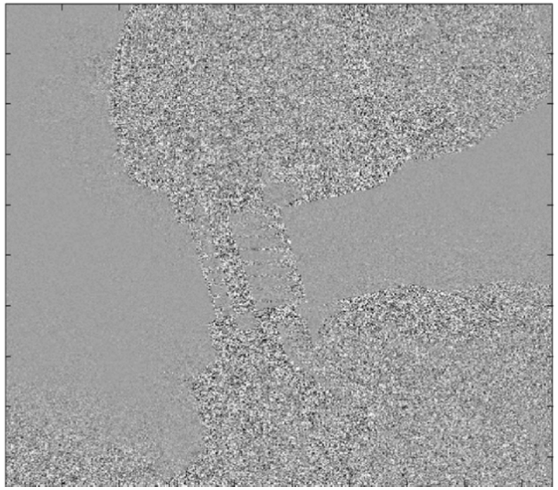


Shot Noise

- The discrete nature of photons results in a variation of the intensity of the incident light as viewed on a photon by photon basis as a function of time
- The variation is the cause of photon shot noise or shot noise as it is also known
- The more intense the image, the greater is the shot noise
- Shot noise is inherent in the image and cannot be avoided and represents the noise floor
- Shot noise in a final image can be eliminated by combining multiple images

IMAGE

PHOTON SHOT NOISE



Fixed Pattern Noise

- For a flat field exposure, any modulation observed that remains constant from frame is Fixed Pattern Noise (FPN)
- For perfect flat-field illumination of the sensor the FPN observed is caused by variations in the photoresponse of each pixel. This represents the floor of the FPN of the system
- For the camera installed on a practical optical imaging system, variations of light intensity are generally observed
  - Non-uniform light intensity across the frame (ie, “hot centers”)
  - Dust motes
  - Filter transmission variations
- These Optical FPN components add to the FPN inherent in the sensor and frequently dominate the overall FPN of the system
- Once FPN dominates the noise of the image, collecting additional signal does not improve the Signal to Noise Ratio (SNR). FPN places an upper limit on the SNR of the system unless removed
- FPN is removed via Flat Fielding (explained later)

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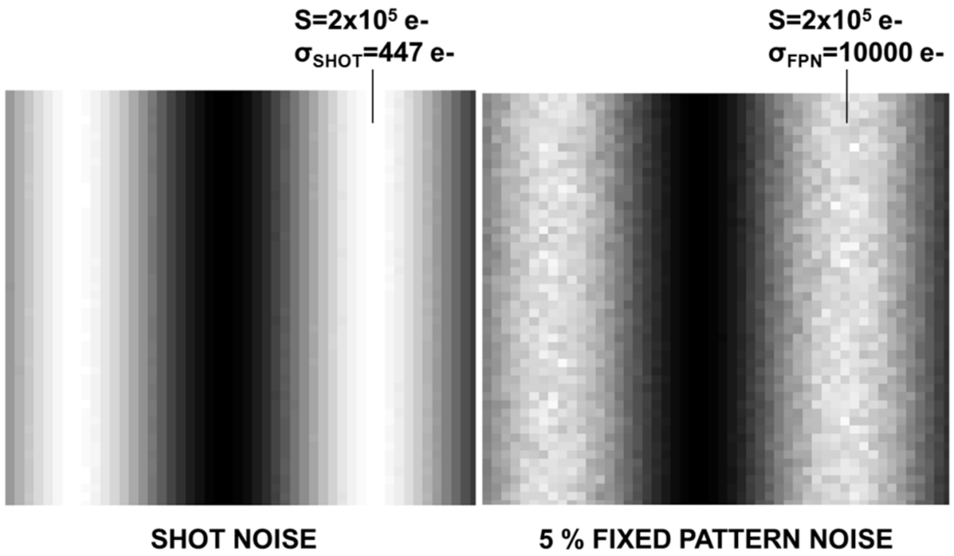
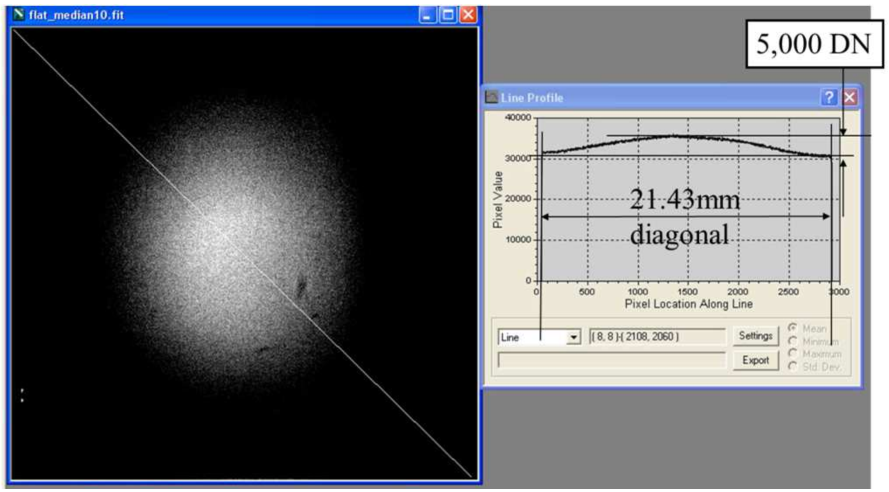
Examples of Fixed Pattern Noise



Sensor FPN

Optical FPN



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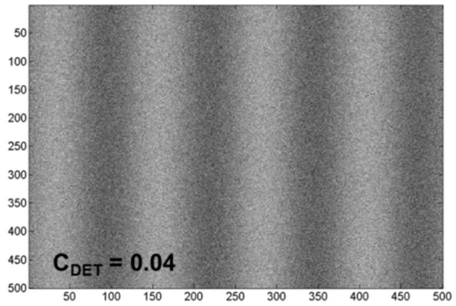
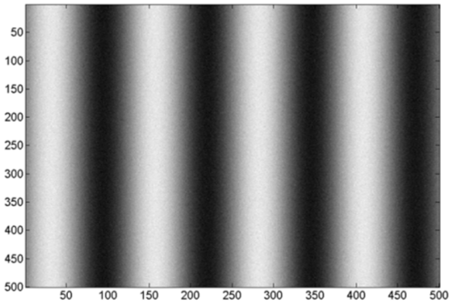
Flat Fielding for FPN Removal

RAW

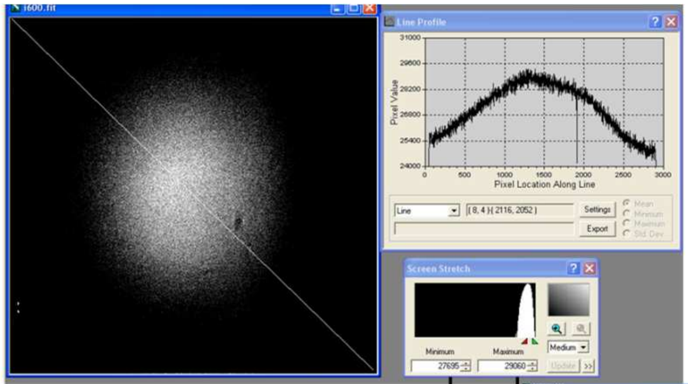


CORRECTED

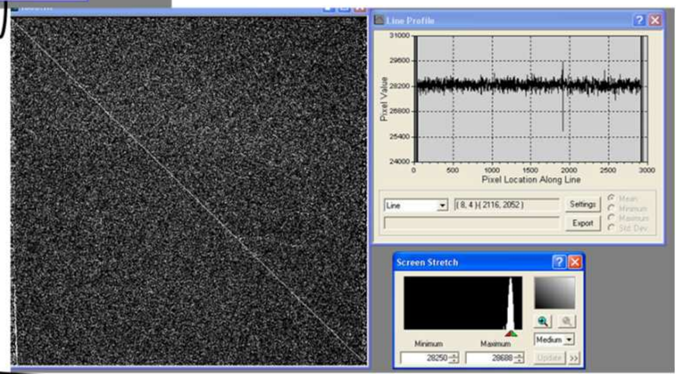


Sensor FPN removal

Optical FPN removal



More uniform light distribution than measured lens before Flat field: less noise at outer parts of image post/flat field



Tighter range of data values than measured lens in image DN histogram prior to flat field operation

Very tight range of data values in image DN histogram after flat field operation

Noise Equation

- To quantitatively analyze noise it must be described mathematically
- When combining the effects of multiple noise sources that are uncorrelated, quadrature summation is used (square root of the sum of the squares of the noise from each separate source)

Noise Equation*

$$Total\_Noise = \sqrt{(read\_noise)^2 + (signal\_shot\_noise)^2 + (fixed\_pattern\_noise)^2}$$

- Assumptions:
  - Flat field target: no modulation
  - Dark signal sources are negligible

Noise Equation Cont'd

$$Total\_Noise = \sqrt{read\_noise^2 + signal\_shot\_noise^2 + fixed\_pattern\_noise^2}$$

recognizing:

$$Signal\_Shot\_Noise = \sqrt{signal}$$

$$Fixed\_pattern\_noise = Signal \times PRNU$$

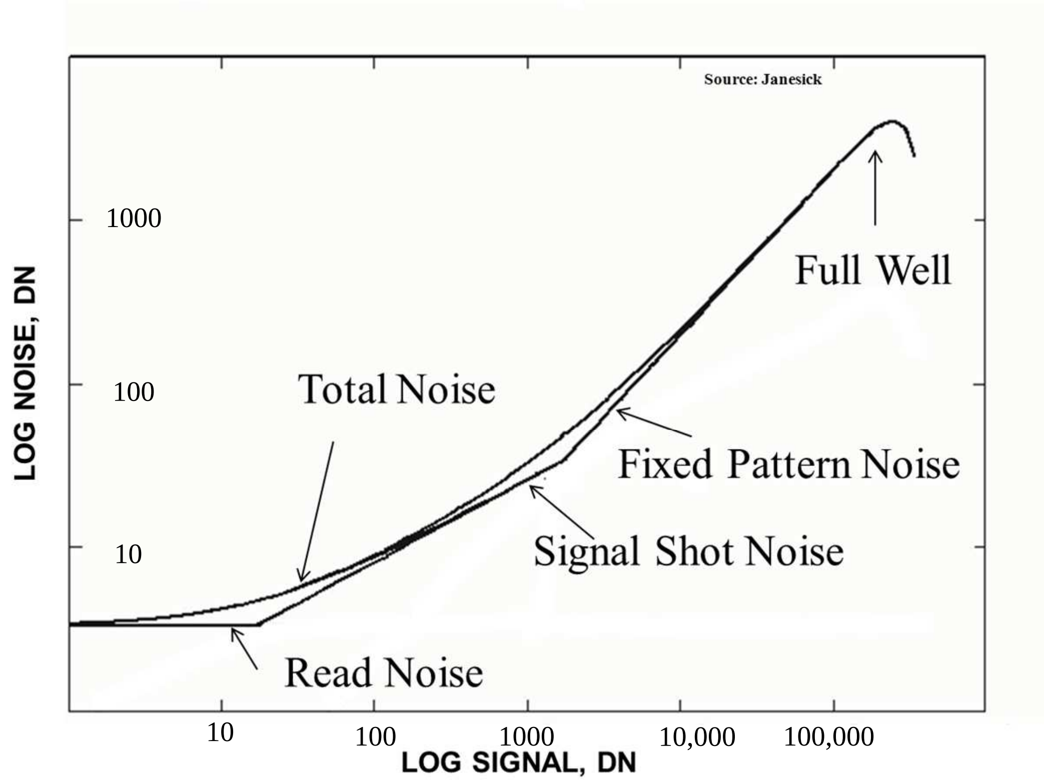
we get:

$$Total\_Noise = \sqrt{read\_noise^2 + signal + (signal \times PRNU)^2}$$

Graphical Representations

- The noise performance of electronic imaging systems is commonly analyzed using graphical techniques
- Noise is plotted on the Y axis with Signal level plotted on the X axis
- Because the noise and signal may range over several orders of magnitude, it is convenient to use logarithmic axes for the plots to accommodate the large range of data extent

Noise Versus Signal



$$Total\_Noise = \sqrt{read\_noise^2 + signal + (signal \times PRNU)^2}$$