Sensor Noise

CPS 1/296

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What is Sensor Noise?

Low noise: http://bellman.cs.duke.edu/~parr/train/20D/normal/IMG_9071.JPG

High(er) noise: http://bellman.cs.duke.edu/~parr/train/20D/normal/IMG_9076.JPG

Talking About Noise

- Engineers are somewhat talking about noise
- Precise way: State distribution over output as a function of luminance (+ environmental factors)
- In practice: Often use SD as a surrogate for this, but it does cause some confusion in some cases

Sources of Sensor Noise

- Dark current (thermal) noise
- Dark current non-uniformity
  - Substrate
  - Environment (amp glow)
- Photon "shot" noise
- Reset noise
- Amplifier noise
  - Pixel level (CMOS)
  - General
- A/D converter noise (not necessarily what you see at high ISO)
  - Noise in converter itself
  - Discretization noise
- Readout noise/losses/electron migration
- General non-uniformity (fixed pattern noise)

Dark Current

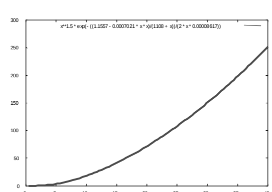
- Dark current is the accumulation of charge unrelated to exposure
- Dark current is proportional to area (more area = more substrate to lose electrons)
- Dark current is proportional to exposure time
- Dark current grows exponentially with temperature

$$D = 2.5x10^{15} A I_d T^{1.5} e^{\frac{E_g}{2kT}}$$

- D = electrons/pixle/s, A = pixel area (cm^2), T = temperature in Kelvin, I_d = reference dark current level (measured at 300K), k= Boltzman's constant, E_g = bandgap of silicon (function of T)

Bandgap vs.Temperature and Dark Current vs. Temperature Plot

$$D = 2.5x10^{15} A I_d T^{1.5} e^{\frac{E_g}{2kT}} \qquad Eg = 1.1557 - \frac{7.021x10^{-4} T^2}{1108 + T}$$



Dark current vs. temp

Note: Shown for trend only. Scale is off b/c A, Id assumed = 1

Modeling Dark Current

- Equation tells us the mean amount of dark current
- What is the distribution?
- Gap between electron release is exponential
- View dark current accumulation as a Poisson process
- Conclusions:
  - Variance = mean
  - SD = sqrt(mean)

Dealing with Dark Current

- Why do camera manufacturers count their pixels in a funny way?
- http://www.dpreview.com/news/0701/07012507olympusp550uz.asp#specs
- Sensors have an optically shielded border of “dark” pixels
  - Can be used to estimate dark current level
  - Subtract off mean dark current value

Understanding Dark Current Subtraction

- Suppose dark current level is x
- Large number of pixels used to estimate x means our estimate of the mean is pretty good
- Each pixel has:
  - Mean “extra” brightness of x
  - SD of extra brightness is sqrt(x)
- After subraction, each pixel has
  - Mean “extra” brightness of 0
  - SD of extra brightness very close sqrt(x) (why not more?)

Dealing with Non-uniformity

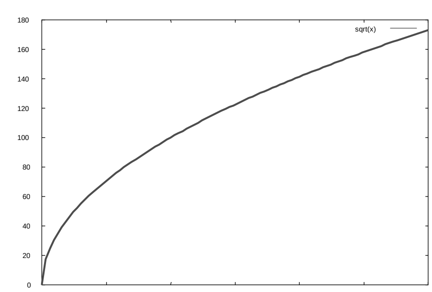
(for dark current, but generalizes)

- Suppose I_d is different for each pixel
- Border pixels don’t tell the full story
- Use double sampling:
  - Take one regular shot
  - Take a second shot of same duration w/shutter closed
  - Subtract
- Modeling the noise:
  - Suppose dark current level is x
  - Both exposures are independent samples
    - Mean x
    - SD = sqrt(x)
  - After subtraction
    - Mean dark current = 0
    - SD = 1.4 sqrt(x) Why is this different from the previous slide?

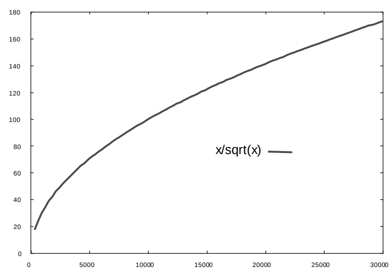
Photon Shot Noise

- Electron liberation by photons is also a Poisson process
- Mean charge generated is proportional to luminance
- Since Poisson, SD(sqrt(mean))
- Counterintuitive result: Brighter areas and brighter scenes have more noise!?!?

Noise vs. Luminance



Signal to Noise Ratio



SNR Comments

- Our perception of noise comes from low signal to noise ratio, not high total noise
- Brighter exposures have more total noise, but higher SNR
- Larger pixels also have more total noise (dark current proportional to area)
- Also have higher SNR since (intended) charge generation also proportional to area

General Comments

- Shot noise, dark current most easily measured sources of noise – tend to dominate in consumer devices
- Why do large digital SLRs produce nicer images? Larger pixels, higher SNR
- What is happening as pixels get smaller(higher MP cameras?)
  - Lower SNR
  - Smaller fraction of pixel captures light
- So, are cameras getting worse? Not necessarily:
  - Sources of noise reduced through engineering
  - Pixel architecture changes can reduce area lost
  - Improved microlenses
  - Software noise reduction (sometimes hurts)