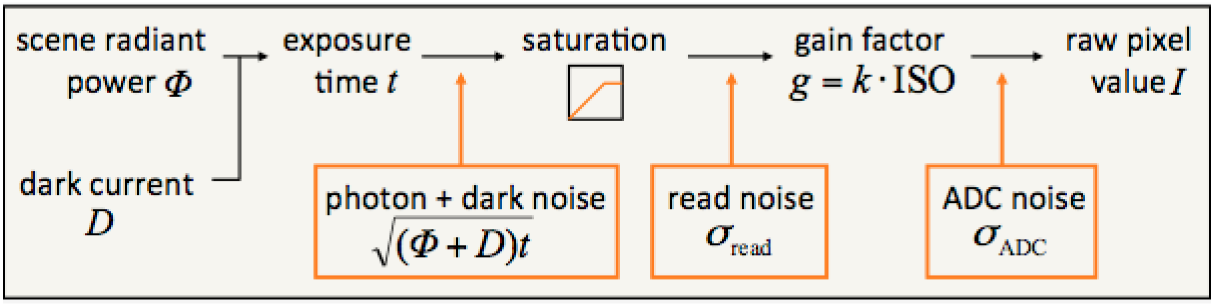
HW2: Measuring the sensor noise of your Tegra tablet (15 Points)

Due: Thursday 10/15/15 at 11:59pm

EECS 395/495: Introduction to Computational Photography



The sensor noise model discussed in the lectures. In this homework assignment, we will measure the photon, read, and ADC noise.

The goal of this homework is to measure and characterize the temporally varying noise properties of the camera on your Tegra tablet. In particular, we are going to compare the signal-dependent (photon) and signal-independent (read, ADC) noise. For the purposes of this homework, the brightness value for the i^{th} pixel is modeled as:

$$I_i = (\phi_i \cdot t)g + n_i \quad \textbf{(1)}$$

where ϕ_i is the power incident on the i^{th} pixel (measured in photo-electrons/sec), t is the exposure time, g is the camera sensitivity (measured in gray levels/photo-electron), and n_i is the noise at the i^{th} pixel. Note that this equation relates a physical quantity (photons) to the digital number stored in a photograph. I_i will fluctuate with time due to noise. However, if we capture N images and average the signal over all measurements, we will get a result that is very close to the desired brightness

$$\mu_i = \frac{1}{N}\sum_{j=1}^{N} I_i^{(j)} \approx (\phi_i \cdot t)g \quad \textbf{(2)}$$

The variance in the measurements is a characterization of the noise in the sensor and is given by

$$\sigma_i^2 = \frac{1}{N}\sum_{j=1}^{N}\left(I_i^{(j)} - \mu_i\right)^2 \quad \textbf{(3)}$$

Note that each pixel in the image will have a different mean μ_i and variance σ_i^2. Our goal will be to calculate these values. There are two components to this homework:

1. Write android code to capture a sequence of images (5 Points)

You will gather sensor noise data by capturing a sequence of images of a static scene. Since the scene brightness will not changed between captured photos, variations in the measured brightness must be due to sensor noise.

You will need to write a program to capture a sequence of images on your tegra tablet. Here are some guidelines:

1. Using the backbone code we provided in hw1. Hint: Look for the TODO:hw2 stubs.
2. Make sure that you don't have any fluorescent lamps lighting your scene. The light output of these lamps actually varies as a function of time, albeit at very high frequencies that we can't perceive.
3. Make sure that your scene contains a relatively wide range of brightness values. Ideally your scene will contain at least one pixel with each possible brightness value between 0-255. For instance, your scene can simply be a print of the following ramp pattern

Figure 1: A ramp pattern generated in Matlab using *repmat(linspace(0, 1, 255),[255 1])*

4. Capture images in the raw file format. Note that this means the bayer pattern will be visible in the images, but you can ignore this.
5. Capture ~ 50 images of the scene
6. Repeat this experiment twice for two different camera sensitivity settings(gain), first set the sensitivity(gain) to the minimum setting, and then the maximum setting.

2. Process the image sequence to gather noise statistics (10 Points)

Now that you have captured a sequence of images, you will need to download them from your device and load them into Matlab. Now write Matlab code to perform the following functions:

1. To load the raw images into MATLAB, you only need to do : t = Tiff(filename,'r') im = read(t). And then im will be the image input. Note: if the image is too large you can sample a part of them (using crop for im) in matlab.
2. For each pixel, you captured a sequence of measurements. Plot a histogram of these pixel values for a given pixel (you can use MATLAB's built in function *hist*). This plot serves as an estimate of the Probability Distribution Function (PDF) for the noise. Create a few plots for different pixels. What do you observe about the PDF? What is its approximate shape?
3. Use equations (2) and (3) to calculate the mean μ_i and variance σ_i^2 for each pixel in the image. Do this separately for each experiment (i.e. for the different gain

settings). Include a figure that shows both the mean and variance images, as well as a few of the original images you captured.

4. Plot the variance as a function of the mean for each experiment. Before you do this, first round the mean values to the nearest integer. There will then likely be several pixels that have the same mean value. Calculate the average variance for this mean value. Recall from class that the noise variance should consist of photon, read, and ADC noise and obey the following model:

$$\sigma_i^2 = (\phi_i \cdot t)g^2 + \sigma_{read}^2 \cdot g^2 + \sigma_{ADC} \quad \mathbf{(4)}$$
$$= \mu_i \cdot g + \sigma_{read}^2 \cdot g^2 + \sigma_{ADC}^2 \quad \mathbf{(5)}$$

   So we expect that when we plot the variance vs. the mean the result will be a straight line where the slope is the camera gain *g*.

5. For each experiment, fit a line to the plotted data. You can do this using the built-in MATLAB function polyfit. For example, if your mean values are stored in a vector *x* and your variance values are stored in a vector *y*, your function call would be *p = polyfit(x,y,1)*.
6. Use your fitted line data to calculate the camera gain *g,* the read noise variance σ_{read}^2 (measured in photo-electrons), and the ADC noise variance σ_{ADC}^2 (measured in gray levels).
7. Signal-to-Noise Ratio (SNR) is a measure of the quality of captured images. It is usually defined as the ratio of signal mean to its standard deviation.

$$SNR = \frac{\mu}{\sigma} \quad \mathbf{(6)}$$

   Plot the SNR as a function of mean pixel value. What is your interpretation of this plot? How does it relate to the three types of noise from equations (4) and (5)? What is the maximum SNR that can be achieved by the Tegra camera?

What to Submit:

Submit a zip file to the dropbox, which includes

1. A write-up document that explains what you did, what the results are, and what problems you encountered.
2. All code that you wrote, including the android code running on the Tegra tablet, and the Matlab code to evaluate the noise statistics.
3. The write-up should include all the figures that you were instructed to generate, and should answer all the questions posed in this document.