Determining a Baseline for Consistent Image Analysis Across Smartphones

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1 Aperture

To gather consistent data from different types of smartphone cameras, we must establish a baseline for the image intensity to be able to normalize pixel data. The varying focal lengths and f-number provide a challenge to make the data normalized.

Consider a measurement done using a particular smartphone. The irradiance or incoming light would be calculated using the aperture area of the sensor. The irradiance is inversely proportional to the aperture area and thus inverse squarely proportional to the aperture diameter.

The amount of light is also dependent on the light cone which is also proportional to the distance to the object. Assuming all the measurements are done at a constant distance, we can solely focus on the variance in the sensor aperture.

The paraxial irradiance, I_C of an image is proportional to $I_c \propto \frac{D_A^2}{F^2}$, where D_A is the aperture diameter and F is the focal length of the sensor.

The ratio of F and D_A is defined as the relative aperture and we can use it to relate different sensors with differing sensor focal lenghts.

1.1 Relative Aperture

The finite size of a lens limits the amount of light it can collect at ny given time. Higher integration times (discussed later) offer linear responce up to a certain time (Schwarzchild Limit).

The exposure depends on thing time t and the irradiance I_C of the light falling onto a sensor location at the image plane C. The amount of fluc (photon lines) admitted into the sensor zone is propotional to the area of the aperture A and thefore the square of the diameter D_A.

A point O of an image is one apex of a solid angle cone whose base is the system aperture area. Therefore a larger diameter increases the base of the flux cone and increases the amount of flux wihin the cone collected by the lens.

Since a higher focal length also increases the length of the cone and therefore decreases the incoming flux, we can define $f_\#$ as the f-number to measure the relative aperture of the camera, where $f_\# = \frac{D_A}{F}$.

We can see that the irradiance is only a measure of this relative aperture accross all devices.

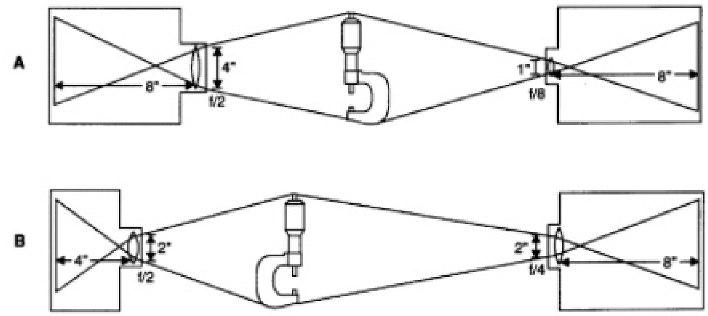


Fig. 3.28 Comparisons of systems differing in relative aperture, focal length, and aperture diameter (after Swedlund, 1974).

Figure 1: From, Image Acquisition: Handbook of machine vision engineering:, Volume 1 by M.W. Burke, Effect of aperture in differing systems.

In image (28.A) we see that sensors with the same focal length, and thus the same magnification. The sensor with f_2 relative aperture will have 16 times the incoming light flux and therefore, brightness compared to f_8.

In (28.B) we have sensors with different focal lengths and therefore different magnifications. Due to the larger focal length, the image must be placed further away from the 8" focal length sensor. Due to the change in distance, the incident light flux and brightness is again only due to the relative aperture. In this case, the sensor with f_2 will have 4 times the incoming light flux and brightnesss compared to f_4

2 Image Sensor

2.1 Introduction

A key factor in consistent image analysis with images from different devices and therefore different image sensors is the metrics of the sensor themselves. Image sensors are generally built upon silicon diodes. The energy bandgap of silicon 1.1 eV is very well suited for the capturing visible light spectrum (45o nm -650nm), which have the photon energies of 2.75eV to 1.9eV. The current line up of smartphones almost universally imply Back-Side Illuminated (BSI) CMOS (complementary metal oxide semiconductors) architecture.

2.2 Integration Time or Shutter Speed

The measure of light hitting the sensor, we must measure the current generated by the photon hitting the sensor. The output voltage measured by the photodiode, is given by,

$$V_{\text{out}} = V_{\text{photo}} - \frac{i_{\text{photo}} t_{\text{int}}}{C_D}[1] \tag{1}$$

V_{out} is the output voltage and V_{photo} is a known potential to aid in voltage detection. i_{photo} is the photocurrent, t_{int} is the integration time, and C_D is the capacitance of the photodiode.

The capacitance and current are usually in the same order (femto), so the integration time t_{int} is linearly proportional to the voltage measured. The integration time is related to the shutter speed and at faster speeds we have the linear relationship with intensity. To normalize intensity captured across devices, we can define a model integration time, t_0 and say,

$$I \propto \frac{T}{T_0} \tag{2}$$

where, T is the integration time or shutter speed used for the image.

2.3 Pixel Metrics

Image sensors essentially convert photons to charges. The variance in the sensors ability to convert photons would cause a variance in the image measurement.

The current generation from photons is not a fully efficient mechanism. The **Quantum Efficiency** measures the efficiency of photon conversion for particular wavelengths. In our particular case, the efficiency at wavelengths of high absorbance for chlorophyll and CDOM can be significantly different across devices. The amount of photons being being detected by the sensor would be essentially a linear function of the integration time or shutter speed and the efficiency at some wavelength. We can define a constant the efficiency, n_0 for any wavelength between $0 \leq n_0 \leq 100$. So we can say that

$$I \propto \frac{n_\lambda}{n_{0\lambda}} \tag{3}$$

Where, $n_{0\lambda}$ is our model efficiency and n_λ is the efficiency for a sensor at wavelength, λ.

2.4 Pixel Size

The pixel size of a sensor referes to the physical single single absorbing photons. The larger the sensor size, the larger the pixel size and more light the pixel can absorb. The intensity of light absorbed is therefore proportional to the surface area covered by the pixel or the square of the pixel size..

3 Smartphone comparisons

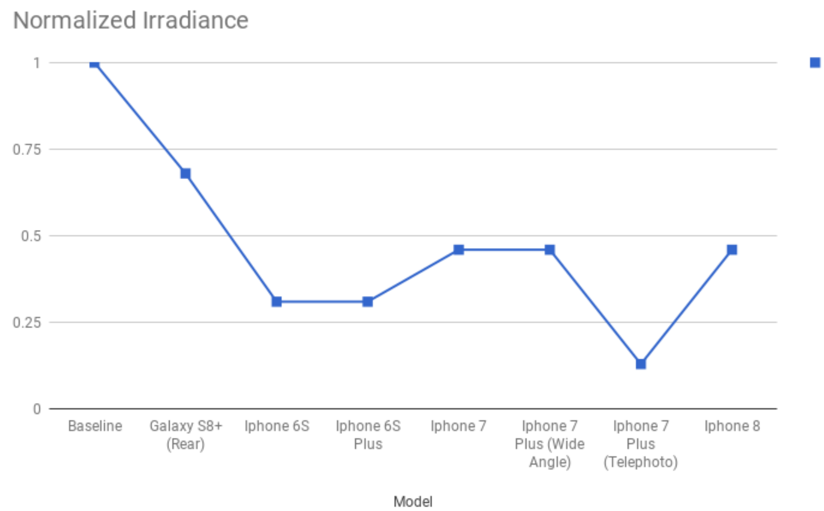
The overall light gathering capabilities of the sensor is defined by the ratio of the focal length to the effective aperture of the system. We define that as the f number of the system. We also have a variance in the sensor size and pixel size on various smartphones. The pixel size has a direct squared relationship with irradiance.

We choose a baseline model smartphone with an Irradiance Factor (IF) of 1, The irradiance factor of a sensor is computed by the ratio of the Pixel size (PS) squared over the Aperutre/ F number squared. The focal length (FL) as discussed above, is included in the f-number.

Model	IS (MP)	Aperture	PS(μm)	FL(mm)	IF
Baseline	12	1.0	1.00	35	1
Galaxy S8+	12	1.7	1.40	26	0.68
iPhone 6S	12	2.2	1.22	29	0.31
iPhone 6S Plus	12	2.2	1.22	29	0.31
iPhone 7	12	1.8	1.22	28	0.46
iPhone 7 Plus (WA)	12	1.8	1.22	28	0.46
iPhone 7 Plus (Telephoto)	12	2.8	1.00	56	0.13
iphone 8	12	1.8	1.22	28	0.46

Table 1: Specifications and Irradiance factor for widely used smartphones

Given the IF, we can see the intensity of light collected by each sensor given the same environment and shutter speed.



We can thus transform the pixel data using the IF to obtain consisten data while using different cameras.

4 Further Notes

Up until this point, we have been considering resulting images that were exactly the same. That means we have been changing sensor positions from the image plane (distance from image), according to the sensor focal length to obtain identical images. Images taken from varying distances must be normalized by their relative magnification and therefore, we must establish a baseline magnificaiton value.
-Will add more smartphones for comparison.
-Research ISO ranges and shutter speed ranges for various Smartphones
-Most of the data is from third party so reliability is an issue.

5 Related Works

5.1 Smartphone Flourescence Spectroscopy

Yu, Tan, and Cunningham demonstrate a procedure to use smartphones for spectrophotometry of flourescence based biolological assays. Ther device involves a collecting lense and diffraction grating to "manually" seperate the incoming wavelength. Although their setup is designed for mobile lab use, and would not be applicable for field testing,the image analysis provides and result show the relative competence of smartphone cameras in detecting visible light for analysis. Image processing for the flourescence photospectrometer involved only a 850x180 band of pixel values from a incandescent lamp (150W halogen fiber-optic high intensity illuminator; Cole Parmer, IL, USA). Interestingly, they obsersved intensity fall offs at two particular wavelengths, 510 nm (cyan) and 580 nm (yellow), even though the incandescent light should produce continuous intensity. A light source fed through a tube with a diffraction grating could serve as a quick tool to measure relative efficiencies of sensors.
The image analysis after obtaining the diffracted images was done after the RGB values were transformed to Hue-Saturation-Value (HSV) to obtain photon intensities at particular wavelength bands. This could possibly be a good avenue to find intensities from RGB in our measurements (After some normalization of course).
`http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.717.9937&rep=rep1&type=pdf`

6 References

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6.1 smartphone specs

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